FINAL

Technical Protocol for Determining the Remedial Requirements for Soils at Small-Arms Firing Ranges

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division (AFCEE/ERT)
Brooks Air Force Base, Texas

August 2000

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Prepared for:

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Brooks Air Force Base, Texas

Prepared by:

Parsons Engineering Science, Inc.
Denver, Colorado

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/dL	micrograms per deciliter
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence, Technology Transfer Division
ARAR	applicable or relevant and appropriate requirement
AS	Air Station
ASTM	American Society of Testing Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BAF	bioaccumulation factor
bcy	British cubic yards
bgs	below ground surface
BRA	baseline risk assessment
CalEPA	California Environmental Protections Agency
CAMU	corrective action management unit
CAP	corrective action plan
CDC	Centers for Disease Control
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm^3	cubic centimeter
CMS	corrective measures study
COC	chemical of concern
COPC	chemical of potential concerns
CSM	conceptual site models
CTT	closed, transferred, and transferring
CU	University of Colorado
DDESB	Department of Defense Explosive Safety Board
DERP	Department of Environmental Restoration Program
DOD	Department of Defense
EE/CA	engineering evaluation/cost analysis
EPC	exposure-point concentration
EPCRA	Emergency Planning and Community Right-to-Know
ERA	ecological risk assessment
FFS	focused feasibility study
FR	Federal Register
FS	feasibility study
GFAAS	graphite furnace/atomic absorption spectrum
HEAST	Health Effects Assessment Summary Table
HI	hazard indices
HQ	hazard quotient
HRA	human health risk assessment
HSA	hollow-stem auger

HWIR	Hazardous Waste Identification Rule Remediation Waste Management Requirements
ICP	inductively coupled plasma
IDW	investigation-derived waste
IEUBK	Integrated Exposure Biokinetic Uptake
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
LDR	Land Disposal Restriction
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest-observed-effect concentration
MEP	multiple extraction procedure
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeters
NCEA	National Center for Environmental Assessment
NCEL	Naval Civil Engineering Laboratory
NCP	National Contingency Plan
NFA	no further action
NOAEL	no-observed-adverse-effect level
NOEC	no-observed-effect concentration
NPL	National Priorities List
OD	outside-diameter
OSHA	Occupational Safety and Health Administration
PAH	polynuclear aromatic hydrocarbon
Parsons ES	Parsons Engineering Science, Inc.
ppm	parts per million
PRG	preliminary remediation goals
PUFS	plant uptake factors
RAGS	Risk Assessment Guidance for Superfund
RAO	remedial action objective
RAP	remedial action plan
RBC	risk-based concentrations
RCRA	Resource Conservation and Recovery Act
RD	remedial design
RI	remedial investigation
RPM	remedial project managers
RRS	risk-reduction standard
S/S	stabilization/solidification
SLHI	screening-level hazard index
SLHQ	screening-level hazard quotient
SMDP	scientific/management decision point
SPLP	synthetic precipitation leachate procedure
SSL	soil screening values
TCLP	toxicity characteristic leaching procedure
TNRCC	Texas Natural Resource Conservation Commission
TRI	toxic release inventory

TRV	toxicity reference value
TRW	Technical Review Workgroup
TSDF	treatment, storage, and disposal facility
USAF	United States Air Force
USEPA	United States Protection Agency
XRF	X-ray fluorescence

SECTION 1

INTRODUCTION

This technical protocol document has been prepared by Parsons Engineering Science, Inc. (Parsons ES) to summarize methods for site characterization, risk analysis, and remedial technology evaluation at abandoned small-arms firing-range sites. This protocol has been prepared to provide guidance for use by United States Air Force (USAF) remedial project managers (RPMs) and their subcontractors in mitigating potential environmental hazards associated with Air Force firing ranges in a cost-effective manner. The project was performed for the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) under Contract No. F41624-97-C-8005.

The demonstration of a risk-based approach to remediation is part of a nationwide USAF initiative to develop a standardized approach for the streamlined assessment and cleanup of Air Force small-arms firing ranges. Numerous Air Force installations have inactive or abandoned firing-range sites that present a potential regulatory concern because of elevated concentrations of metals (especially lead) in site soils. Traditionally, these sites have undergone a costly and time-consuming multiphase investigation process, including remedial investigation (RI), baseline risk assessment (BRA), feasibility study (FS) or corrective measures study (CMS), and remedial design (RD). The purpose of this initiative is to establish a technically sound and uniform approach to firing-range site investigation, risk evaluation, and remediation that potentially is more cost effective and efficient than the conventional remedial process.

The risk-based approach described in this protocol provides a cost-effective strategy for remediation of metals (primarily lead) and potentially other analytes of concern at small-arms ranges that is protective of human health and the environment. The risk-based approach has been applied at four former range sites as part of this initiative. The demonstration sites included small-arms practice ranges in California, Texas, and Alaska; and a skeet range in Texas (Table 1.1). The remediation strategy described herein incorporates the "lessons learned" during these evaluations, and was developed with careful consideration of the nature and dispersion of site contaminants that are typical for small-arms firing-range sites. This strategy provides an approach that is consistent with the Air Force objective of providing a protective yet cost-effective remedial approach for soils at small-arms firing ranges at Air Force installations.

The overall goal of remedial activities at small arms firing-range sites is protection of human health and the environment within an overall cost-effective approach. The realization of this goal is impacted by several aspects that are unique to firing-range sites:

- Remedial action is frequently necessary for firing range sites, and the area requiring remediation is generally the soil within the projectile "drop zone" (i.e., the impact

TABLE 1.1
DEMONSTRATION SITES

Site	Site Description
Small-Arms Range, California	• Target range • 2.8 acres • Used between 1950s and 1970s • Backstop berm was removed by 1985 • Future industrial land use
Small-Arms Range, Texas	• One of eight rifle and pistol ranges • 2.8 acres • Used between 1956 and 1981 • Backstop berm approx. 300 ft long by 20 ft high • Future residential land use
Small-Arms Range, Alaska	• Target range in gravel pit • 5 acres • Used prior to 1984 • Backstop berm approx. 125 ft long by 15 ft high • Future industrial or open space land use • Range floor and berm covered with fly ash
Skeet Range, Texas	• Recreational skeet range • 25 acres • Used from 1960s to 1980s • Flat terrain • Future industrial land use

berm for rifle/pistol ranges or the area with highest shot concentration in skeet/trap ranges).

- Due to the persistent nature of lead contamination, remedial actions at small sites typically focus on soil removal actions. Therefore, the selected waste management approach can have a significant impact on the overall remediation strategy.

- Scoping and investigation activities should focus on minimization of the volume of media (i.e., soil) that requires handling, treatment and/or disposal.

In addition, documentation of project scoping (i.e., a project work plan), data evaluation (i.e., a remedial action plan), and verification (i.e., a close-out report) are

important aspects to the management of small-arms firing-range sites, as well as for any other remediation site. These aspects are further incorporated into the approach described in this protocol.

1.1 DESCRIPTION OF RANGES

Typically, small-arms firing ranges used for rifle or pistol practice consist of a firing line (where trainees are positioned), a target line, and an impact berm located behind the target line (also referred to as a backstop berm) (see Figure 1.1). Some rifle ranges may also have a low-lying target berm along the target line that is used to protect target structures or personnel during training. The distance from the firing line to the target line is normally 25 to 100 yards for pistol ranges, and 100 to 1,000 yards for rifle ranges. Impact berms vary in height from 5 feet to as high as 50 feet, with an average height of approximately 20 feet. Soil volumes in these impact berms can range from less than 100 cubic yards to as much as 20,000 cubic yards (Heath *et al.*, 1991). The footprints of the sites evaluated ranged from less than 1 acre for a small pistol range to almost 25 acres for a full-size rifle range (a 30-position range with a 1,000-yard firing line). Combat training ranges with "pop-up" or moving targets are configured differently than rifle or pistol ranges; the distribution of bullets will be systematically distributed in a unique pattern dependant on the training scenario and target arrangement.

Typical operational maintenance at target range facilities includes the periodic disking of site soils, recovery of spent munitions from the berm areas, repairing berm erosion caused by storm events and repeated impact from regular training use, and removal and replacement of berm areas to reduce ricochet problems. These procedures typically are not well documented at abandoned sites, but may be reflected in the overall distribution of the contaminants at the site. The potential for soil contamination at a firing range is directly proportional to the degree to which the range was used (i.e., the number of rounds per year fired into the impact berm). The US Army has developed software for assessing the need for range maintenance based on the amount of use and other parameters such as soil type and annual precipitation (US Army Environmental Center, 1997).

Another type of small-arms range encountered at some Air Force bases is the skeet or trap range where shotguns are used to fire at airborne targets (i.e., clay disks or "clay pigeons;" see Figure 1.2) launched from the sides (skeet) or center (trap) of the range. Because the locations of launch stations are standardized, shot and target fragments are distributed in a fairly uniform pattern across the ground surface. Skeet and trap ranges normally do not have impact berms. As a result, shot typically is distributed in a widely dispersed pattern rather than concentrated in one target area. The range areas requiring characterization typically cover up to 20 acres or more, although the areas requiring remediation may be considerably smaller.

1.2 COMPOSITION OF PROJECTILES AND CHEMICALS OF POTENTIAL CONCERN

Chemicals of potential concern (COPCs) that may be present in soils at rifle and pistol ranges due to historical activities are associated with the four main components of small-arms ammunition: the cartridge case; the cap; the propellant; and the projectile. A rifle

FIGURE 1.1

SCHEMATIC CONTAMINANT DISTRIBUTION FOR TARGET RANGES

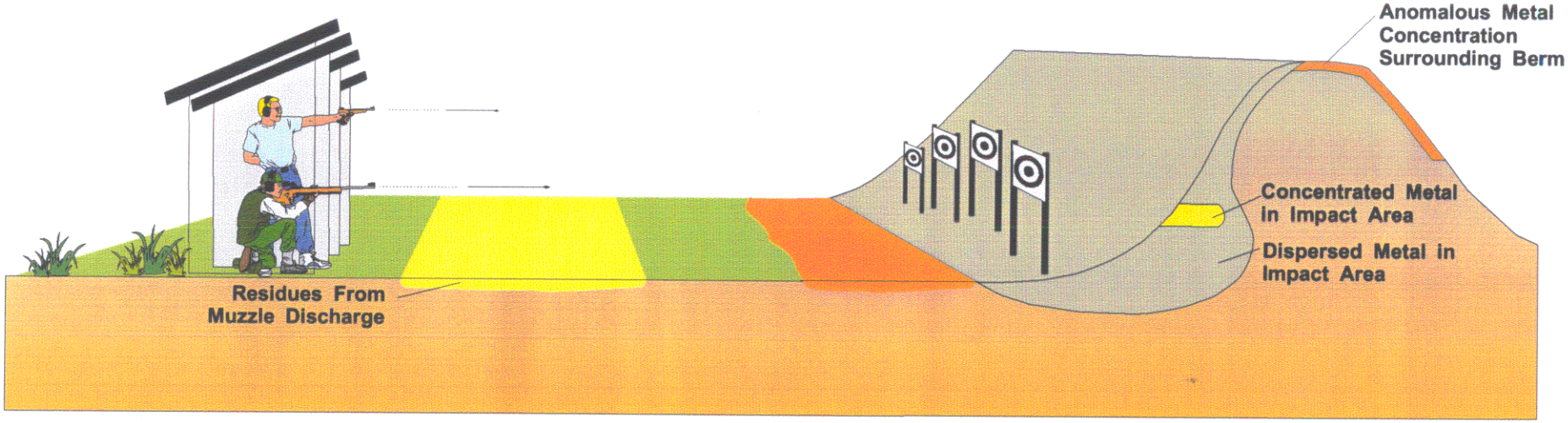

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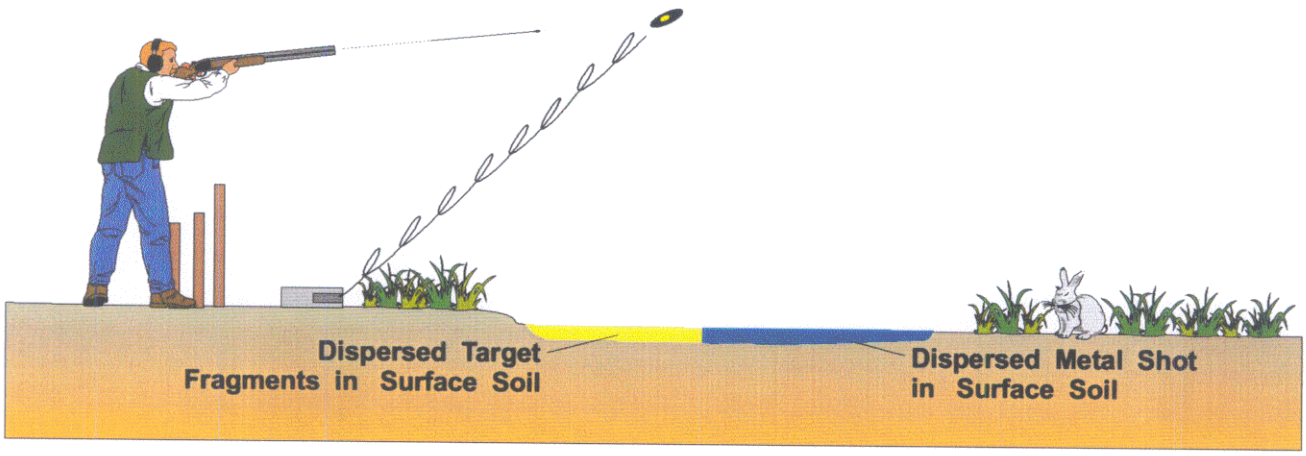
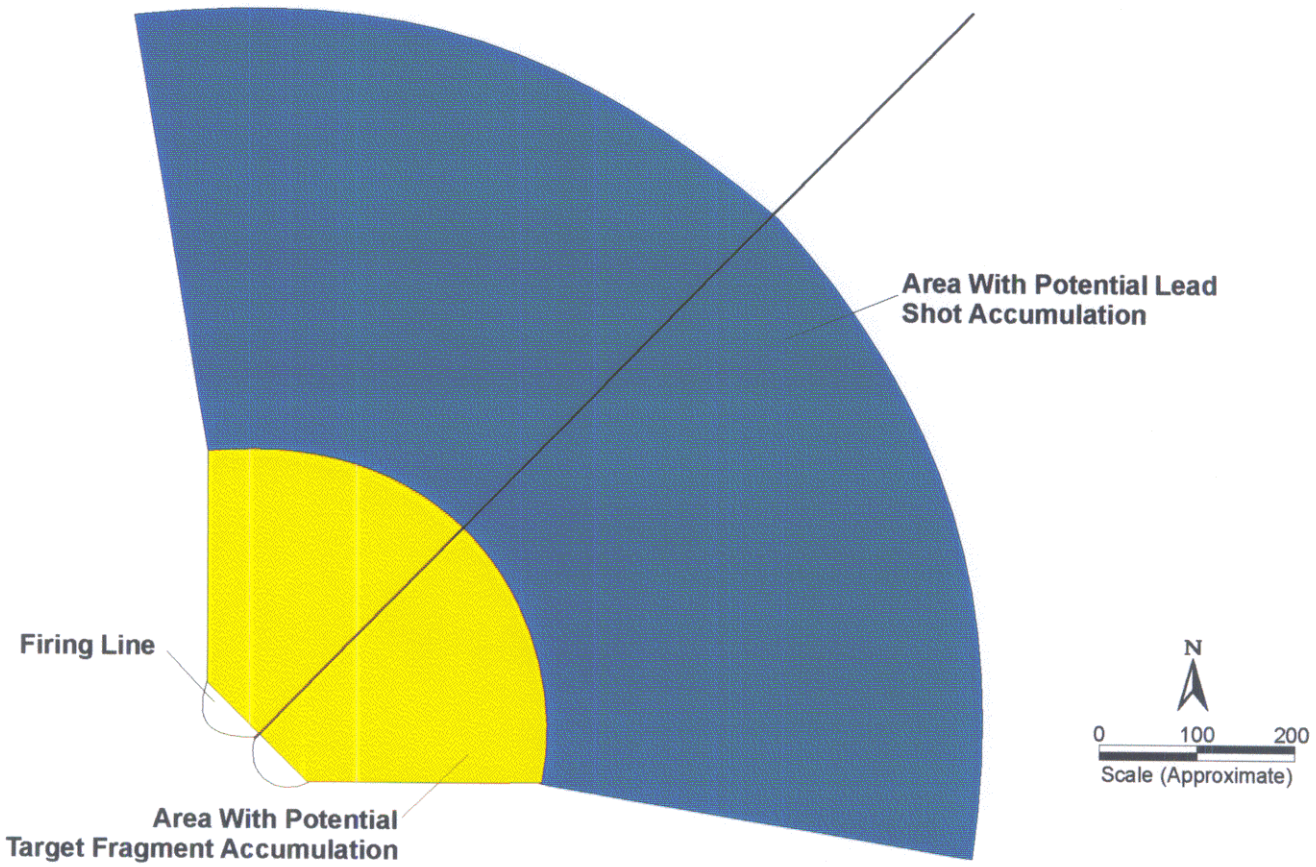
FIGURE 1.2

CONTAMINANT DISTRIBUTION FOR SKEET RANGES



Schematic Cross Sectional View



Plan View

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bullet has a lead core with up to 15 percent antimony added for hardness (Ross, 1980). Metal-jacketed bullets are used in high-velocity and automatic weapons such as M16 rifles and M60 machine guns. The outer metal jacket usually is either copper-plated or covered with a thin layer of gilding metal. There are various grades of gilding metals, in which copper and zinc are the major components. Therefore, metals constituting significant mass fraction in a bullet are lead, copper, zinc, and antimony (Heath *et al.*, 1991).

Rifle cartridge cases historically have been constructed of either brass (zinc and copper) or aluminum. These cases normally would be found near the firing line (discharge area), where they are extracted or ejected after firing. The cap or capsule, which is the part of the cartridge case that holds an explosive (propellant) mixture, is made of either copper or brass. A nonvolatile product of propellant combustion that may be present in range soils is barium (as barium nitrate) (Burrard, 1951; Corbin, 1979). Therefore, based on bullet compositions the metals that may be of concern at firing ranges include copper, zinc, barium, lead, and antimony. Nickel also was included as a COPC during the Air Force risk-based demonstrations based on reports of nickel as a constituent in jacket materials. However, the presence of nickel is not substantiated in most references, and this metal was not encountered in significant concentrations in the site soils evaluated (Table 3.1). Based on this review, the following hierarchy of soil COPCs was assumed for firing-range sites:

- Primary Concern: lead (based on high concentrations); and
- Secondary Concern: antimony , barium, copper, and zinc.

The target analytes in any investigation will depend on the munitions used at the site and the prevailing regulatory requirements. However, this hierarchy of COPCs should be used when developing a sampling and analysis plan for pistol/rifle firing-range sites. Additional analytical parameters may be required based upon site-specific considerations. For example, historical solvent use at a nearby location for weapons cleaning and maintenance may indicate the need for analysis of volatile organic compounds (VOCs) in soils and/or groundwater. Also, firing ranges may be located adjacent to landfills or other industrial activities; therefore, there may be a need to analyze for parameters associated with the adjacent site use that could impact remedial activities.

Because unjacketed or "bare" lead often is used as shot in shotgun shells, lead also is a primary COPC at skeet and trap ranges. Target disks or "clay pigeons" are composed of mineral powder held together with an asphalt-like petroleum pitch binder. Concentrations of polynuclear aromatic hydrocarbon (PAH) compounds in target disks are on the order of 1,000 milligrams per kilogram (mg/kg) (Baer *et al.*, 1995). The presence of PAHs in soils due to target fragments was confirmed during the risk-based evaluation of a skeet range in Texas (Table 3.1)

1.3 DISTRIBUTION OF CONTAMINANTS

Under AFCEE's risk-based initiative, site characterization activities were performed at four small-arms range sites (including one skeet range). A summary of the investigation techniques and maximum detected concentrations of analytes in soils is presented in

Table 1.2. The distribution of contaminants at the demonstration sites is similar to other literature reports on firing-range sites, as summarized below.

Lead contamination at small-arms firing ranges usually consists of a large quantity of lead accumulated in a relatively small volume of soil (Edmonds, 1993). Generally high levels of lead (from greater than 1 percent up to 30 percent) are concentrated within the impact berm. A major portion of the lead in the berm exists as large bullet fragments, but also may be present as fine particulates, smeared lead, and weathering products (Johnson *et al.*, 1993). The soil gradation within the protective berms in target ranges is likely to have an impact on lead distribution. In a study of three comparable sites, bullets were found almost entirely whole with the copper coat intact in a "beach sand," while bullets were more fragmented in coarser material (Johnson *et al.*, 1993).

Elevated levels of metals (especially lead) also can be found between the firing line and the target berm (undershot) and beyond the target berm (overshot) (Figure 1.1). Small amounts of lead, zinc, and copper contaminants (residues from the muzzle blast) also accumulate near the firing positions as the small-arms are fired. The ratio of metal contaminants in soil associated with the firing line is expected to be similar to the composition of bullets used (i.e., higher concentrations of lead relative to other metals). Further, the concentration of metals near the firing line is expected to be directly proportional to the level of training range use (i.e., ranges with a smaller volume of use are likely to have comparatively low levels of contaminants in firing line soils).

The fallout and accumulation of these contaminants are also influenced heavily by wind conditions. Physical transport mechanisms such as aerial dispersion and surface water runoff also can affect the distribution of contaminants in soils surrounding the firing line and berm areas. Whole or fragmented bullets are often recovered in the berm area, with decreasing concentrations away from the berm. At some sites, stormwater runoff plays a large role in distributing contaminants throughout the site, following the surface drainage patterns.

Vertical distribution of lead and other metals usually is limited to the first 1 or 2 feet of the soil column. However, vertical distribution patterns (and to a lesser extent horizontal distribution patterns) at some sites may be driven by maintenance activities (e.g., disking of site soils), which result in physical disturbances that can introduce elevated metal concentrations into deeper soils (Edmonds, 1993; Naval Civil Engineering Laboratory [NCEL], 1990). Distributions of the individual constituents (primary and secondary COPCs) of ammunition in soils generally are similar to each other (i.e., areas with high antimony or copper concentrations also will have elevated lead concentrations).

Environmental conditions also can significantly affect the mobility and fate of firing-range contaminants in soils. Firing ranges located in the eastern or southeastern regions of the US may have enhanced migration of lead and other metals in soils due to moister climates and more acidic soils. In contrast, sites located in the western US often have lower potential for contaminant migration due to drier climates and more alkaline soil conditions. Arid sites have a greater potential for windblown dispersion of soil contaminants. Erosion of an impact berm due to precipitation in wetter climates, or wind dispersion in drier climates, can result in transport of metal contamination away from the berm. Sites evaluated under this initiative typically exhibited elevated metals

TABLE 1.2
SMALL-ARMS FIRING RANGE SITE CHARACTERIZATION

Site	Site Description	Investigation Techniques	Maximum Concentrations Detected in Soil
Small-Arms Range, California	• Target range • 2.8 acres • Used between 1950s and 1970s • Backstop berm was removed by 1985 • Future industrial land use	• Surface and subsurface (hand auger) soil sampling • Field XRF [a/] analysis for metals • Laboratory analysis for metals	• Lead (surface soil): 39,900 mg/kg • Lead (subsurface soil): 384 mg/kg at 1.5 to 2 ft bgs • Antimony: 77.2 mg/kg • Barium: 307 mg/kg • Copper: 4,930 mg/kg • Nickel: 25.1 mg/kg • Zinc: 513 mg/kg
Small-Arms Range, Texas	• One of eight rifle and pistol ranges • 2.8 acres • Used between 1956 and 1981 • Backstop berm approx. 300 ft long by 20 ft high • Future residential land use	• Surface and subsurface (hollow-stem auger rig) soil sampling • Backhoe sampling within berm • Laboratory analysis for metals	• Lead (surface soil): 98,400 mg/kg • Lead (subsurface soil): 11,700 mg/kg at 4 to 4.5 ft bgs • Lead (in berm): 65,600 mg/kg at 4 to 6 ft bgs • Antimony: 1,330 mg/kg • Barium: 1,300 mg/kg • Copper: 34,800 mg/kg • Nickel: 19.2 mg/kg • Zinc: 3,880 mg/kg
Small-Arms Range, Alaska	• Target range in gravel pit • 5 acres • Used prior to 1984 • Backstop berm approx. 125 ft long by 15 ft high • Future industrial or open space land use • Range floor and berm covered with fly ash	• Surface and subsurface (hollow-stem auger rig) soil sampling • Backhoe sampling within berm • Field XRF analysis for lead • Laboratory analysis for metals	• Lead (surface soil): 112 mg/kg • Lead (subsurface soil): 30.8 mg/kg at 1 to 1.5 ft bgs • Lead (in berm): 195 mg/kg at 0 to 0.5 ft bgs • Antimony: 1.8 mg/kg • Barium: 848 mg/kg • Copper: 47.5 mg/kg • Nickel: 28.6 mg/kg • Zinc: 61.3 mg/kg
Skeet Range, Texas	• Recreational skeet range • 25 acres • Used from 1960s to 1980s • Flat terrain • Open space/Future industrial land use	• Surface and subsurface (hand auger) soil sampling • Removal of shot from samples with No. 10 sieve • Laboratory analysis for metals and PAHs [b/]	• Lead (surface soil): 524 mg/kg • Lead (subsurface soil): 110 mg/kg at 1 to 1.5 ft bgs • Antimony: 5.3 mg/kg • Barium: 164 mg/kg • Copper: 15.2 mg/kg • Nickel: 15.9 mg/kg • Zinc: 69.2 mg/kg • Benzo(a)pyrene (surface soil): 4,200 mg/kg • Dibenz(a,h)anthracene (surface soil): 1,500 mg/kg

[a/] XRF = X-Ray fluorescence

[b/] PAHs = polynuclear aromatic hydrocarbon

concentrations surrounding the impact berm, with high concentrations of metals in surface soils that rapidly decreased with depth.

Metallic lead that is initially present as bullets, bullet fragments, or shot in soil is insoluble in water, and therefore does not significantly migrate in the aqueous environment (except by physical transport of metallic lead particles, as discussed above). However, metallic lead is thermodynamically unstable in the near surface geochemical environments, and therefore has the tendency to be chemically transformed into other lead species and complexes that are more soluble in water than metallic lead. The rate of chemical dissolution and mobility of lead in the subsurface (such as vertical transport to groundwater) is thus controlled by a number of interacting geochemical processes including oxidation/reduction, precipitation/dissolution, adsorption/desorption, and complexation/chelation (SAAMI, 1996). The prediction of the resulting migration of lead in the subsurface is therefore a complex endeavor, and various prediction models have been prepared for estimating the vertical migration of metals (including lead) in soil (see USGS, 2000 for example).

Skeet and trap ranges typically cover approximately 25 acres in a fan-shaped area with a maximum radial dimension of 900 feet from the center of the firing line (Figure 1.2). The shape and acreage of a site can be estimated using historical aerial photographs and general knowledge about the typical scatter patterns of shot and target debris at skeet/trap ranges (Peck *et al.*, 1998). Based on the results of this initiative (Table 1.2) and other skeet-range studies, metals-contaminated soil at skeet and trap ranges is expected to be greatest between approximately 300 and 650 feet downrange from the firing line. The highest concentrations of PAHs from target debris typically are generally located closer to the firing range than the shot concentrations. Random sampling of locations outside the areas of concentrated shot/target fallout is recommended to characterize the areas surrounding the zone of higher impact. Shot and target debris distribution, and soil lead and PAH contamination, are expected to be greatest in surface soils (Peck *et al.*, 1998).

Soils from firing-range sites may exceed the toxicity characteristic leaching procedure (TCLP) criteria for characteristic hazardous waste (40 Code of Federal Regulations [CFR] 261.24), which can significantly impact remediation requirements at these sites. Table 1.3 presents the minimum and maximum concentrations from TCLP lead analyses of soil samples (generally from the impact berm area) for the four demonstration sites evaluated under this initiative. TCLP testing of source-area soils is a recommended component of any firing-range evaluation to determine appropriate waste-management requirements.

1.4 OVERVIEW OF RISK-BASED APPROACH

The fundamental steps in the risk-based approach applied to firing-range sites are presented in Figure 1.3, and are as follow:

- Determine the appropriate regulatory requirements and prepare scoping documents;

TABLE 1.3
MINIMUM AND MAXIMUM TOXICITY CHARACTERISTIC LEACHING PROCEDURE METALS RESULTS
(all units in mg/kg)

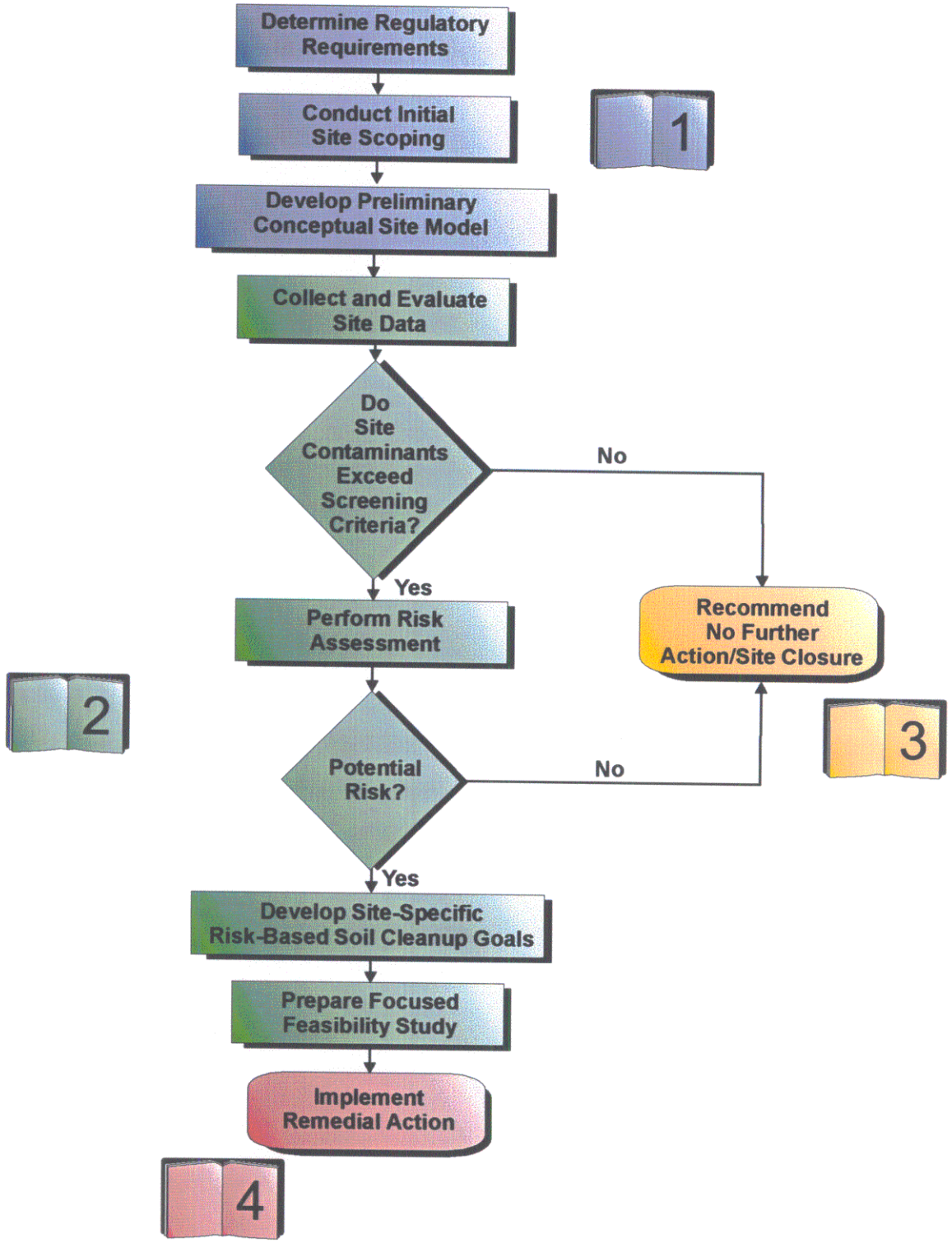
		Small-Arms Ranges			Skeet Range	Regulatory Threshold
		California	Texas	Alaska	Texas	
Arsenic	min.	not analyzed	0.0032	0.0036 UJ[a/]	0.012J	5
	max.	not analyzed	0.088	0.007 J	0.365J	
Barium	min.	not analyzed	1.34	1.85 J	1.52J	100
	max.	not analyzed	3.52	5.620 J	2.21J	
Cadmium	min.	not analyzed	0.00046	0.00043 UJ	0.00092J	1
	max.	not analyzed	0.0043	0.00081 J	0.0011J	
Chromium	min.	not analyzed	0.005U	0.006 J	0.0058J	5
	max.	not analyzed	0.076	0.0181 J	0.032J	
Lead	min.	**14.6** [b/]	0.0941U	0.0027 UJ	0.0536	5
	max.	**92.5**	**1050**	2.8 J	**7.61**	
Mercury	min.	not analyzed	0.00013U	not analyzed	not analyzed	0.2
	max.	not analyzed	0.00015	not analyzed	not analyzed	
Selenium	min.	not analyzed	0.003U	0.0021 UJ	0.0021	1
	max.	not analyzed	0.0097	0.0021 UJ	0.0034J	
Silver	min.	not analyzed	0.003U	0.0037 UJ	0.0037	5
	max.	not analyzed	0.003U	0.0037 UJ	0.0037 U	

[a/] U = Analyte not detected, J =

[b/] Concentrations exceeding regulatory limits are in **bold**.

FIGURE 1.3

RISK-BASED APPROACH FOR DETERMINING REMEDIAL REQUIREMENTS AT SMALL ARMS FIRING RANGES



Required Documentation

1 Work Plan	3 No Further Action Decision Document or Risk-Basd Site Closure Report
2 Remedial Action Plan	4 Can Include Proposed Plan, Record of Decision, and Close-Out Report

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- Collect and analyze site soil samples to characterize the nature and extent of metals contamination;
- Conduct assessments of potential risks to human and ecological receptors exposed to contaminated site media;
- Develop risk-based soil cleanup goals that are protective of human health and the environment;
- Conduct a focused feasibility study (FFS) to develop and evaluate alternatives for remediation of metals contamination in site soils, and recommend a remedial strategy for site soils; and
- Implement remedial action based on the results of the FFS.

A summary of key tasks for firing range remediation, as well as estimated schedule durations and parties responsible for the tasks, are presented in Table 1.4.

1.5 DOCUMENT ORGANIZATION

This protocol consists of eight sections, including this introduction, and six appendices:

- Section 1 provides background information and the objectives of this protocol document.
- Section 2 provides a description of regulatory requirements for small-arms ranges.
- Section 3 describes the development of a conceptual site model (CSM) and summarizes site characterization activities.
- Section 4 describes the human health and ecological risk assessment process.
- Section 5 describes the development of soil cleanup goals for firing-range sites.
- Section 6 describes the FFS process.
- Section 7 is a discussion of common deliverables required in this process.
- References are provided in Section 8.
- Appendix A provides a discussion of the conceptual site models (CSMs), data usability, and exposure-point concentrations (EPCs) used in the risk assessments.
- Appendix B provides a detailed description of the methodology used for the human health risk assessments (including risk algorithms).
- Appendix C provides the results of bioavailability assessments conducted for the firing-range sites evaluated under this initiative.
- Appendix D summarizes lessons learned for ecological risk assessments.
- Appendix E describes a simulated remediation approach for determining the volume of soils requiring remediation.
- Appendix F is an example soils treatability study work plan.

TABLE 1.4
SUMMARY OF KEY TASKS FOR REMEDIATION AT SMALL ARMS RANGES

Key Task	Approximate Duration	Responsible Party	Notes
Determine regulatory framework – RCRA, CERCLA, voluntary cleanup (*Following tasks assume CERCLA process*)	6 months	Air Force with Contractor support	
Initial regulatory contact	2 hours	Air Force with Contractor support	
Prepare work plan: • Records review • Assess site conditions and land use • Review existing analytical data • Develop initial conceptual site model • Develop sampling/analysis strategy • Propose risk exposure parameters • Prepare written plan • Air Force and regulator review and comment • Regulatory scoping meeting	6 months	Contractor with Air Force and regulatory approval	SMDP [a/]
Evaluate need for EOD Clearance	6 to 18 months	EOD Contractor	See note [b/]
Field data and sample collection	1 to 2 weeks	Contractor	
Laboratory analysis and data validation	8 weeks	Contractor	
Treatability study	8 weeks	Contractor	
Compile database and query data for analysis	2 weeks	Contractor	
Identify COPCs (frequency of detection, site-attribution analysis and toxicity screening)	2 weeks	Contractor	SMDP
Determine exposure areas and exposure-point concentrations	2 weeks	Contractor	
Human health risk assessment: • Hazard identification • Exposure evaluation • Toxicity evaluation • Risk characterization	8 weeks	Contractor	SMDP
Ecological risk assessment: • Problem formulation • Analysis • Risk characterization • Risk management	8 weeks (concurrent with human health risk assessment)	Contractor	SMDP
Develop numerical/non-numerical risk-based cleanup goals (if warranted): • Assess state and federal ARARs • Calculate risk-based cleanup levels • Assess goals from risk management perspective	2 weeks	Contractor	SMDP

TABLE 1.4 (CONTINUED)
SUMMARY OF KEY TASKS FOR REMEDIATION AT SMALL ARMS RANGES

Key Task	Approximate Duration	Responsible Party	Notes
Perform focused feasibility study: • Remedial action objectives • Determine if interim remedial action or full closure applies • Volume of soil requiring remediation • Technology screening • Assess treatability study results • Develop/analyze remedial alternatives • Select preferred alternative	8 weeks	Contractor	SMDP
Prepare remedial action plan (or, if warranted, no further action closure report): • Prepare written report • Air Force and regulator review and comment	6 months	Contractor with Air Force and regulatory approval	
Proposed Plan	4 months	Air Force with Contractor support	SMDP
Record of Decision or Decision Document	6 months	Air Force with Contractor support	
Procure and Implement Remedial Design/Remedial Action	18 months	Air Force/Contractor	
Prepare Remediation Close-Out Report	6 months	Contractor	
Long-term monitoring (if required)	To be determined	Air Force/Contractor	

[a/] SMDP = Scientific management decision point.

[b/] EOD clearance is not typically required but may cause substantial impact to project schedule if high-explosive components are discovered. Small arms ammunition (e.g., unfired small-arms cartridges) is not a basis for EOD investigation.

SECTION 2

REGULATORY REQUIREMENTS

2.1 REGULATORY OVERVIEW FOR LEAD

Lead is a principal component of bullets used at small-arms firing ranges. Consequently, assessment and cleanups at these sites focus predominantly on the presence of lead in soils and other environmental media. Lead is chemically stable and is not biodegradable. High levels of lead and lead compounds are known to induce disease and toxicity in high-risk receptors (e.g., children, pregnant women) (US Environmental Protection Agency [USEPA], 1991a, 1994a, and 1994b). The Center for Disease Control (CDC) has repeatedly lowered the human blood lead level of concern, from 40 micrograms per deciliter (µg/dL) in 1978, to 25 µg/dL in 1990, to the current blood lead level of concern of 10 µg/dL.

To date, a nationally recognized "safe" lead concentration in environmental media has not been developed. Lead is ubiquitous and can occur naturally in surface and shallow soils at concentrations ranging from 5 to 50 parts per million (ppm). Therefore, USEPA has focused predominantly on reducing the potential for sensitive populations to be exposed to anthropogenic (man-made) lead sources (e.g., industrial emissions, leaded gasoline, lead-based paint) and environmental media contaminated with lead as a result of human activities (e.g., sites of mineral extraction and smelting operations, and potentially, firing ranges).

In 1991, USEPA issued a strategy memorandum describing the agency's goal of reducing lead exposure to the fullest extent practicable in the US, with particular interest in reducing the risk to children. Two objectives were used to set USEPA's lead-reduction program priorities:

- Significantly reduce the incidence of blood lead levels above 10 µg/dL in children, while taking into account the associated costs and benefits; and

- Significantly reduce, through voluntary and regulatory actions, unacceptable lead exposures that are anticipated to pose risks to children, the general public, or the environment.

In addition to regulations intended to protect sensitive human populations, USEPA and most states developed surface water quality standards for lead that are intended to be protective of aquatic organisms. To that end, USEPA developed guidelines for assessing the toxicity of lead in sediments to aquatic species. Documented toxicity of lead in game birds has led to state restrictions or bans on the manufacture and sale of lead shot in shotgun shells.

2.2 REQUIREMENTS FOR FIRING-RANGE SITES

It is important to understand the regulatory drivers that govern the assessment of small-arms range sites (Table 2.1). The status of the range (active or inactive) and applicable regulatory framework will significantly impact the cost of range management. *Active* ranges are ranges that continue to be used for munitions training. Inactive ranges are ranges that are no longer used for firing-range activity, but that are still under military control, and have not been impacted by a new land use that is incompatible with potential future range activities. In contrast, a *closed* range is a former firing range that continues to be under military control, but has been changed to an alternative land use that is incompatible with use as a firing range. A *transferred* range is a range that has been removed from military control through deed transfer or other means.

Following is a brief summary of potential regulatory requirements that may apply to a small-arms range site. The regulatory environment is frequently changing and therefore it is important to obtain current and relevant information for your site. For specific Base requirements, it is important to check with your Major Command headquarters as well as the applicable State regulators before proceeding with a regulatory approach.

TABLE 2.1
RANGE MANAGEMENT COSTS AS A FUNCTION OF RANGE STATUS AND REGULATORY FRAMEWORK

Range Status	*Regulatory Framework*	*Basis*	*Restoration Management Cost Impact*
Active	EPA Munitions Rule (RCRA)	Placement of lead from bullets follows intended use (not a waste)	Low
	Toxic Release Inventory[a/]	Reporting of releases includes munitions used in training	Low
Inactive	EPA Munitions Rule (RCRA)	Placement of lead from bullets follows intended use (not a waste)	Low
Closed, Transferred and Transferring	RCRA, CERCLA, DoD Range Rule [not yet adopted]	Site restoration required to protect human health and environment	High
(All Categories)	OSHA	Protect range workers from lead exposure	Low

[a/] See Section 2.2.1.2.

2.2.1 Active and Inactive Ranges

Both active ranges and inactive ranges have common features that can significantly lower the requirements for cleanup: both types of site are under military control, and they are continue to be used (or for inactive sites, are available for use) for small-arms

training. Therefore, there is no compelling reason for cleanup of environmental media located on-Base. Worker protection from lead exposure under the Occupational Safety and Health Association (OSHA) is required; however, based on EPA's Munitions Rule, active remediation of the site to protect general human health and the environment should not be necessary. Instead, site management options (i.e., access controls, monitoring, etc.) can be implemented to reduce the potential risk of exposure to site workers. This can result in significant cost savings in comparison to active remediation of closed or transferred/transferring ranges. Therefore, careful consideration should be given to describing the status of the range before proceeding with environmental restoration activities to allow the most efficient uses of Air Force resources.

2.2.1.1 EPA's Munitions Rule

A key aspect to the regulatory requirements that apply to active and/or inactive firing-range sites is described in the EPA Military Munitions Rule. EPA promulgated the Final Military Munitions Rule on 12 February 1997, 62 Federal Register (FR) 6622. The validity of the Munitions Rule was upheld in *Military Toxics Project v. Browner*, 146 F.3d 948 (D.C. Cir. 1998). The final rule consolidates the requirements applicable solely to military munitions in a new Subpart M under Title 40 of the Code of Federal Regulations (40 CFR), Part 266. States with RCRA authority must adopt the requirements before the rule becomes effective in those states. As of 31 Dec. 1999, 26 States have provisionally adopted either an identical version or variations of the Military Munitions Rule. Of these, three have received USEPA approval—Georgia, Louisiana, and Nevada. You will need to confer with legal counsel concerning any Munitions Rule variations that apply in your State.

The Munitions Rule addresses all ammunition products and components, including small-arms ammunition. Under RCRA regulations set forth in 40 CFR, materials are considered to be hazardous waste if both of the following conditions are met:

- The material is a solid waste, as defined in 40 CFR 261.2, and
- The material meets the definition of hazardous waste in 40 CFR 261.3.

The Munitions Rule specifies that military munitions are not solid waste when they are used for their intended purpose, including use in training military personnel, as well as research, development, testing, and evaluation. Rather, munitions are products used for their intended purpose, even when they hit the ground (which is a normal expectation of their use). Therefore, the presence of lead in soils at active and inactive firing ranges does not result in the soils being considered a solid waste.

The Military Munitions Rule presently has the following implications for the Air Force with respect to small-arms firing ranges:

- Bullets in soils at active and inactive ranges are currently not defined as a solid waste, and therefore would not be considered a hazardous waste while the soils are left in place, even if the soils failed the TCLP test for leachable lead.

- The offsite transport of firing-range soils that contains recoverable lead bullets for offsite recovery of lead and/or disposal currently is defined as a solid waste activity, and therefore would be subject to RCRA hazardous waste transportation and disposal requirements if the soils fail the TCLP test for lead. Conversely, soil containing bullets that is transported offsite but does not fail the TCLP test for lead would not be subject to RCRA hazardous waste requirements, but could be treated/disposed of as nonhazardous solid waste.

- Offsite disposal of residual soil that fails the TCLP test for lead after removal of recoverable lead, or onsite stabilization of contaminated soil to render the soil non-hazardous, would be subject to RCRA hazardous waste regulation.

- The shipment of lead that was removed from soils during a reclamation operation would be considered scrap metal recycling, and would not be subject to hazardous waste regulations.

2.2.1.2 Toxic Release Inventory Reporting

On April 4, 2000, DOD issued Guidance on *Applying the Emergency Planning and Community Right-to-Know (EPCRA) Toxic Release Inventory Requirements to Ranges.* This DOD guidance requires toxic release inventory (TRI) reporting by the military services of toxic releases on military ranges, including releases from active small-arms firing ranges.

The range TRI reporting guidance provides that:

- The first reporting is to occur by 1 July 2002, for releases in calendar year 2001.

- Annual reporting is required for ranges with more than 10 full-time employees involved in the operation, management, or maintenance of the range.

- Reporting is to include munitions used in training (e.g. target practice, live fire exercises, etc.) but does not include small-arms firing for personal use (e.g. private gun club events); research, development, testing, and evaluation of new and existing munitions; or toxic chemicals in targets.

- Munitions constituents that are EPCRA toxic chemicals include energetics, structural substances (e.g., copper in brass); and trace organics.

- Range TRI reporting is to include the intended use of munitions on small-arms ranges as the EPCRA "otherwise use" of toxic chemicals, and these munitions constituents will count toward both the "otherwise use" 10,000-pound threshold, and the "manufacture" threshold of 25,000 pounds.

- If either threshold is exceeded, an installation must determine and report releases, and provide onsite management and offsite transfers of the associated toxic chemicals in accordance with EPCRA.

Policy guidance from a Major Command or Base level may be required to determine the number of employees and the quantity of munitions used for implementation of these reporting requirements at active ranges.

2.2.1.3 OSHA

Persons who may receive occupational exposure to lead at military firing ranges are subject to 26 C.F.R. § 1910.1025 and the related OSHA policies for protection from lead hazards. Such persons are also subject to all other relevant OSHA health and safety requirements. Cleanup of small-arms ranges should follow OSHA occupational health and safety requirements for hazardous waste operations and emergency response (29 C.F.R. § 1910.120).

2.2.2 Closed, Transferred and Transferring Ranges

Small-arms ranges that require regulatory closure or that will be transferred out of DOD control may require restoration to mitigate potential threats posed by lead in soils to human health and the environment. Regulatory programs that could potentially apply to environmental restoration activities include the DOD Range Rule, CERCLA and RCRA. Again, the regulatory approach will need to be developed in consultation with the applicable regulators.

2.2.2.1 DOD Range Rule

In the Preamble of the final Munitions Rule, USEPA advised that it was postponing final action on whether spent munitions in a closed range, or on a range transferred from military control, meet the statutory definition of solid waste in RCRA Section 1004(27) until DOD adopts a range cleanup rule (the "DOD Range Rule") to see how it addresses this issue. DOD published a proposed rule on "Closed, Transferred, and Transferring Ranges Containing Military Munitions," 62 Fed. Reg. 50796 (September 26, 1997) (known generally as the DOD Range Rule). The proposal described the process DOD proposed to use to evaluate appropriate response actions for closed, transferred, and transferring (CTT) military ranges. It would not apply to active and inactive ranges, or to any CTT range that is included on the National Priorities List (NPL) or subject to response activities pursuant to any specific statutory authority.

As of April 2000, DOD has not adopted a final DOD Range Rule. Air Force installations should not endeavor to follow the 1997 proposed DOD Rule in lieu of a final promulgated rule. See also DOD (1998) and (1997).

2.2.2.2 Comprehensive Environmental Response, Compensation, and Liability Act

Cleanup of small-arms ranges should generally follow CERCLA, the NCP (40 C.F.R. part 300), and all relevant CERCLA guidance. Environmental restoration activities at Air Force Bases typically follow a CERCLA-type process under the Installation Restoration Program (IRP).

2.2.2.3 Resource Conservation and Recovery Act

RCRA designates lead and several lead compounds as nonacutely hazardous wastes and/or regulated constituents. Lead and many lead compounds are characteristically hazardous waste as measured by TCLP. RCRA hazardous waste requirements may apply to the handling of lead-contaminated soils at firing-range sites if the soil exceeds the characteristic of toxicity for lead (i.e., fails the TCLP test) and is removed for treatment and/or disposal (Table 2.2).

TABLE 2.2
RCRA STATUS OF SELECTED LEAD-CONTAINING WASTES

Subject to RCRA Hazardous Waste Requirements	*Not Subject to RCRA Hazardous Waste Requirements*
• The offsite transport of firing-range soils for recovery of lead and/or disposal, *if the soils fail the TCLP test for lead.*	• Lead bullets in soils at active and inactive ranges while the soils are left in place, *even if the soils failed the TCLP test for lead.*
• Offsite disposal of residual soil *if the soils fail the TCLP test for lead* after removal of recoverable lead	• Onsite recovery of lead from firing-range soils.
• Onsite stabilization of contaminated soil to render the soil nonhazardous	• Shipment of recovered lead to an offsite smelter, which is *considered scrap metal recycling.*

Treatment of hazardous waste typically requires a RCRA Part B hazardous waste permit. However, hazardous waste generators are allowed to perform treatment in accumulation tanks or containers (e.g., 51 Fed. Reg. 10146, 10168 (24 March 1986). Some secondary lead recovery facilities utilize this rule to stabilize smelter slag with a solidification agent in a tank in order to meet TCLP requirements for onsite disposal. Alternatively, the regulators could establish a RCRA corrective action temporary unit (CATU) for treatment of the waste under 40 CFR Parts 264 or 265. See 40 CFR § 264.553. Establishment of a temporary unit alleviates some of the specific design requirements for treatment units (see 58 FR 8658, 8673 (February 16, 1993). Normally, however, CATUs are established only at RCRA Part B-permitted facilities.

Cleanup under RCRA of a small-arms range should follow the Hazardous Waste Identification Rule Remediation Waste Management Requirements (HWIR-Media), which was adopted on 30 November 1998. Provisions of the HWIR-Media Rule are incorporated directly into the relevant parts of the Code of Federal Regulations, especially into 40 CFR part 270. However, State regulators should be included in the decision making process prior to planning and implementation of remedial activities.

The onsite recovery and collection of munitions fragments (i.e., spent bullet rounds) also are specifically excluded from regulation as solid waste activities under the scrap metals exemption of 40 CFR § 261.6(a)(3)(ii).

SECTION 3

SITE CHARACTERIZATION METHODS

This protocol document outlines a standardized, but flexible, risk-based approach to soil remediation at small-arms firing ranges. A key component of the evaluation process is the assessment of potential risks to human and non-human (i.e., ecological) receptors that may be exposed to firing-range contaminants in site soils under current or future land use scenarios. As noted in Section 2, the NCP, as implemented through the IRP at Air Force installations, requires that releases of hazardous substances into the environment be evaluated and, if necessary, remediated to ensure that chemical residues do not pose a threat to human health or the environment. Because the site characterization and risk assessment efforts are interdependent, project team members (e.g., risk assessors, geologists, hydrogeologists, engineers, and chemists) must work together, and in consultation with the regulatory agency overseeing site cleanup, to ensure that the data collected during the site characterization effort fill data gaps and are of sufficient quantity and quality to be usable for risk analysis and remedial decision-making.

The importance of involving regulators throughout the scoping and execution phases of the risk assessment cannot be overemphasized. The term "scientific/management decision point" (SMDP) has been borrowed from USEPA (1997a) ecological risk assessment guidance to indicate points in the risk assessment process at which regulatory input should be sought before proceeding to the next step.

Scientific/Management Decision Points (SMDPs)

Ongoing interaction with the appropriate regulatory agencies is essential to ensure that assumptions used in the risk assessment, and the results based upon them, are acceptable. Establish SMDPs throughout the risk assessment process to maintain a constructive dialogue with regulators and to minimize rework.

3.1 CONCEPTUAL SITE MODEL

The potential for small-arms firing-range soil contaminants to pose risks to human or non-human receptors is dependent on a number of factors, including site history, current and expected land uses, site ecology, climate, topography, and of course, the magnitude, nature, and extent of soil contamination. Information on most of these factors is gathered before or during work plan preparation (through research and review of available site data) and during field characterization efforts. The conceptual site model (CSM) of potential receptor exposures is a valuable tool for organizing and summarizing site-specific information that will determine which receptors may be exposed to soil contaminants, and how such exposures may occur.

A preliminary CSM is used during scoping to identify data gaps and should be updated as new characterization data become available. The risk assessment, and consequently the site characterization activities, should focus only on those receptors and exposure routes for which pathways are, or are likely to be, completed. Primary considerations for developing a CSM, and questions to be answered when updating the CSM and selecting the receptors to be evaluated in the risk assessment, are discussed in Appendix A. An example CSM for a small-arms range site is presented as Figure 3.1.

3.2 SAMPLING STRATEGY

Field sampling is required to determine the magnitude of impacts from potentially completed exposure pathways identified in the CSM. A recommended sampling strategy is provided in Table 3.1 and illustrated in Figure 3.2. This recommended approach includes field sampling and analytical activities to fill risk-based data needs (i.e., needed to complete the risk assessment) as well as for FFS data needs (i.e., for evaluation of soil management and treatment options). A recommended minimum quantity of each type of sample is provided; however, the sampling strategy must be developed on a site-specific basis to fully meet the data needs of each site.

Discussion of sampling strategy and evaluation techniques throughout this protocol document are generally focused on the risks posed to humans and ecological receptors due to ingestion or inhalation of contaminated soil. However, evaluation of the potential threat to groundwater posed by soil contamination with elevated metals (especially lead) may also need to be considered in the scoping phase. The degree that this evaluation may be required depends largely on three factors:

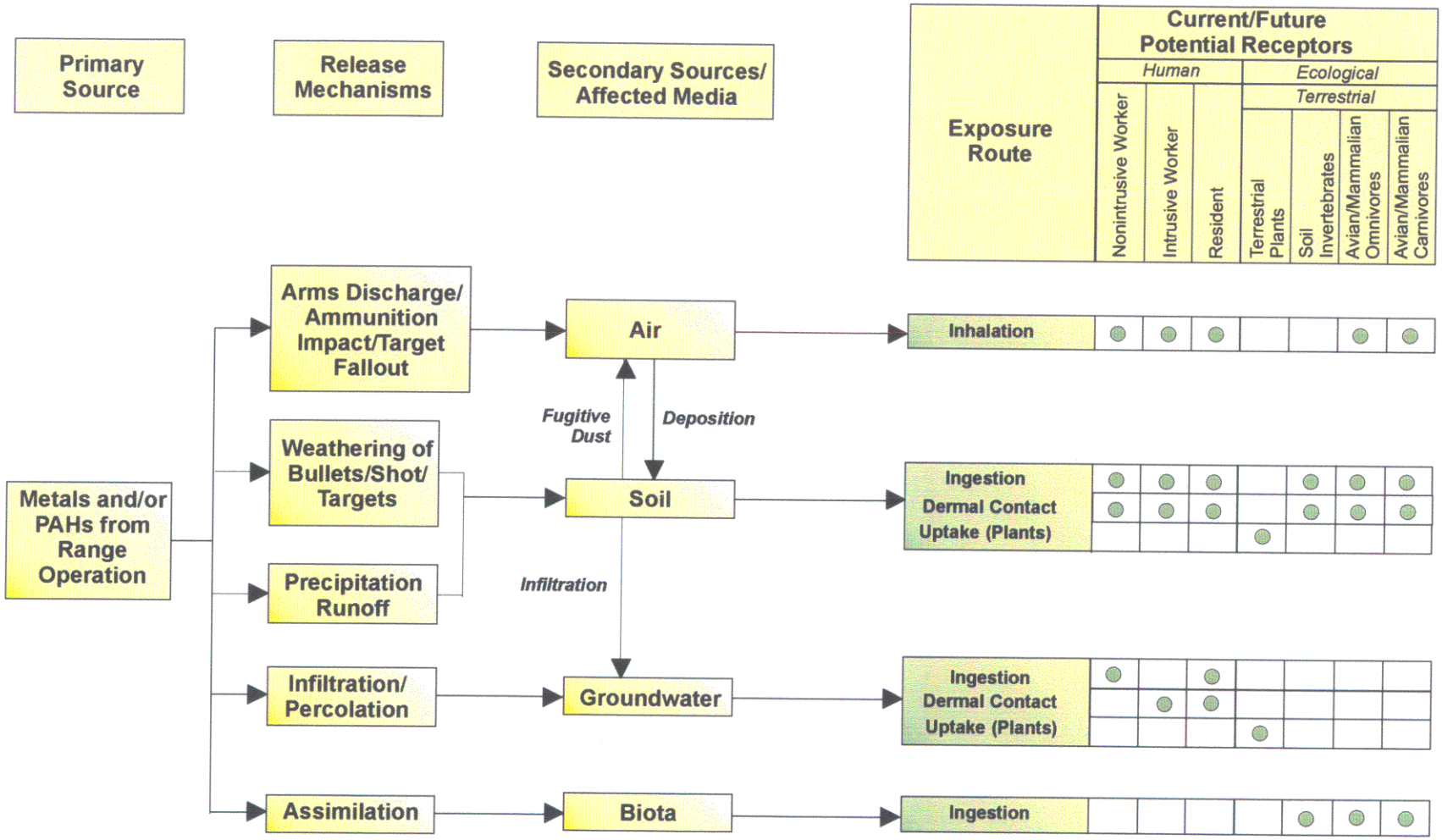
- The depth of groundwater in relation to soil contamination (which is a technical consideration),
- Chemical- and soil-specific properties, and
- The regulatory concern regarding the endangerment of shallow groundwater resources (which is often more of an administrative concern).

Figure 3.2 presents an iterative approach for assessing threat to groundwater. The first consideration should involve subsurface sampling to determine the relative proximity of metals contamination with respect to the depth of groundwater. The second consideration involves collection of representative soil samples for leachate analysis by the synthetic precipitation leachate procedure (SPLP; EPA Method SW1311). SPLP analysis can provide additional information on the potential for leachate generation from contaminated soils, and is recommended particularly where there may be enhanced regulatory concerns about threat to groundwater. However, it is recommended that the soil samples for SPLP analysis be collected from areas or depth intervals outside of the soil volume that is likely to be remediated, so that the results will represent the material left in place rather than grossly contaminated materials that are likely to be removed or treated.

If shallow groundwater (arbitrarily defined as 15 feet bgs or shallower, although another depth may be more appropriate based on site conditions) is encountered at the site, then collection of groundwater samples may be appropriate to provide a more

FIGURE 3.1

EXAMPLE FIRING-RANGE CONCEPTUAL EXPOSURE MODEL (TERRESTRIAL SITE)



Legend

- Potentially completed pathway.
- Incomplete pathway.

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TABLE 3.1
RECOMMENDED SAMPLING STRATEGY FOR SMALL-ARMS RANGES

Risk-Based Sampling Data Needs:

Pathway	Media	Recommended Sampling Strategy	Analytical Parameters
Fugitive dust deposition, ingestion, dermal contact	Surface soil	Composite surface soil (0 to 0.5 ft bgs) samples within 50 ft. grid. Minimum of 30 samples.	Lead; 30% of samples for other metal COPCs[1/]
	Surface soil	At least six randomly selected soil samples.	*In vitro* bioavailability
	Surface soil	At least three randomly selected soil samples.	Lead speciation
	Subsurface soil	Discrete soil sample locations, at two depths (2 to 2.5 and 4 to 4.5 ft bgs). Minimum of 12 samples.	Lead; other metal COPCs[1/]
Infiltration to groundwater	Subsurface soil	Vertical profile soil sampling at 2 ft depth intervals (from 0 to 12 ft bgs). Two vertical profile locations near impact berm.	Lead; other metal COPCs[1/]
	Subsurface soil	Discrete samples for leachability testing. Minimum of four samples; include two samples representative of less contaminated soils to remain after remediation.	SPLP[2/] for lead and metal COPCs[1/]

TABLE 3.1 (CONTINUED)
RECOMMENDED SAMPLING STRATEGY FOR SMALL-ARMS RANGES

Risk-Based Sampling Data Needs:

Pathway	Media	Recommended Sampling Strategy	Analytical Parameters
	Groundwater	Collect groundwater samples from wells or temporary piezometers if groundwater is relatively shallow (i.e., 15 ft bgs or less) (minimum of three samples)	Lead and other metal COPCs[1/]

Focused Feasibility Study Data Needs:

Description	Media	Recommended Sampling Strategy	Analytical Parameters
Soil management options	Surface and subsurface soils	Discrete or composite samples of impact berm and range floor soils. Minimum of four samples.	TCLP[3/] metals and grain size analysis.
Soil treatment options	Surface and subsurface soils.	Bulk composite sample of impact berm and contaminated range floor soils. Minimum of one sample.	Bench-scale treatability testing for particulate lead removal.

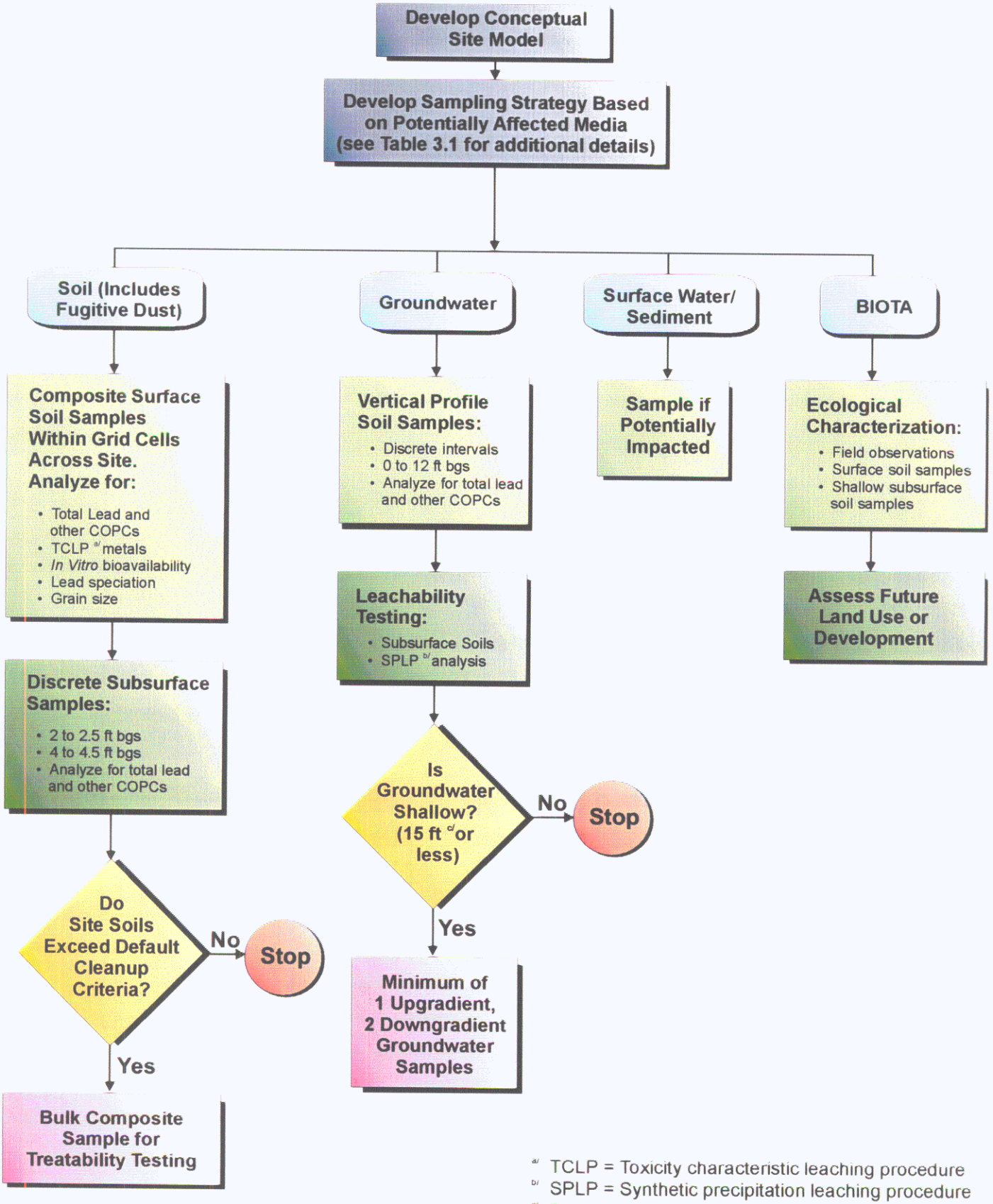
[1/] COPCs = contaminants of potential concern, specifically antimony, barium, copper and zinc. Also include analysis for polynuclear aromatic hydrocarbons if site is a skeet or trap range. Frequency of 30% for non-lead analytes in surface soils is based on providing sufficient data for calculation of exposure point concentrations in surface soils; alternatively, 100% analysis of non-lead analytes may be used.

[2/] SPLP = Synthetic precipitation leachate procedure.

[3/] TCLP = Toxicity characteristic leachate procedure.

FIGURE 3.2

DEVELOPMENT OF SITE CHARACTERIZATION STRATEGY



[a] TCLP = Toxicity characteristic leaching procedure
[b] SPLP = Synthetic precipitation leaching procedure
[c] Based on engineering judgement; site-specific consideration is required

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definitive conclusion on the existing soil-to-groundwater impacts at the site. At a minimum, any groundwater data collection should include at least one upgradient location and two downgradient locations to determine potential site impacts.

3.3 FIELD SAMPLING METHODOLOGY

Characterization of small-arms range sites typically involves the collection and analysis of samples representative of potentially impacted site media (primarily soil, but potentially groundwater, surface water, and sediments). These topics are discussed in additional detail below.

Methods for Improving Data Precision in Soil Samples

- Collect ***bulk*** and/or ***composite samples*** that are representative of defined areas within the range
- Remove larger bullet fragments (or shot pellets at skeet/trap ranges) with ***field sieving*** (see Section 3.3.1.3)
- Include a ***larger aliquot of soil*** (2 grams or greater) for laboratory digestion

3.3.1 Soil Sampling

The following types of soil samples should be collected for adequate characterization of small-arms range sites.

Discrete Samples. Discrete samples consist of soils from a single, unique location and depth. These samples may be composited over no more than a 6-inch vertical interval (or other predetermined interval and weigh approximately 500 grams. These samples should be collected outside the berm area where the spatial variability in lead concentrations is considered much less than within the berm. Discrete samples are prepared in the field by collecting soil from the required interval, thoroughly mixing the soil in a stainless steel pan using a stainless steel utensil, and placing a representative portion of the soil into an 8-ounce sample container.

Bulk Samples. Bulk samples are recommended for the impact berm areas where spatial variability in lead concentrations is considered a significant factor in data collection. Bulk samples also are recommended for treatability study analysis, or for more precise determination of the quantity of metal fragments in soils. Bulk samples can be collected with larger hand tools such as shovels, or with equipment such as backhoes. Bulk samples consist of soils from a single location and composited over a vertical interval of up to 24 inches. Bulk samples will weigh approximately 20 kilograms (i.e., a 5-gallon sample container), or can be carefully homogenized with a shovel or trowel, and then

reduced (by dividing the larger sample into quarter volumes) into an appropriate sample volume. One should continue quartering until the appropriate sample size is obtained.

Composite Samples. Composite samples consist of soils collected from several locations, and can include horizontal or vertical compositing of discrete samples. Sample weight varies based on the analytical requirements. Composite samples have been successfully used to represent surface soils within 50-foot-square grid areas (see Section 3.3.1.1). Composite samples are collected primarily with hand tools such as trowels or shovels. Discrete sample portions of nearly equal mass (generally standardized by collecting the similar volumes from a standard size tool, such as a trowel) are collected from multiple locations, and then thoroughly mixed and homogenized with the sampling tool prior to being placed into containers for transport to the laboratory.

3.3.1.1 Surface Soil

Where's the lead?

At small-arms ranges where soils are the principal affected medium, COPCs are likely to be concentrated in surface soils.

Based on the results of this and other studies at small-arms ranges, the highest concentrations of lead and other metals in site soils generally are encountered in surface soils (herein defined as 0 to 0.5 foot below ground surface [ft bgs]). A recommended practice for surface soil sampling consists of collecting composite samples prepared by combining an aliquot of surface soil collected at five randomly selected locations within 50-foot-square grid cells that are defined across the site. Soil is collected at a depth of 0.5 foot bgs using a stainless steel trowel, mixed (i.e., homogenized) in a stainless steel bowl, and placed into sample containers. Aliquots of soil collected from the soil impact berm containing visible metal fragments should be weighed, sieved, and the sieved fractions reweighed in the field prior to mixing, to account for metals removed during sample processing.

3.3.1.2 Subsurface Soil

Due to the limited mobility of metals and PAHs in soils, it is likely that the surficial contamination at small-arms range sites will be rapidly attenuated with depth. However, contamination in subsurface soils (greater than 0.5 ft bgs) may be encountered due to a variety of reasons, including:

- Mixing of surface soils with deeper soils through maintenance practices (e.g., tilling or grading) or natural processes (e.g., frost heave or animal burrowing);
- Accumulation of bullets and bullet fragments within the interior of the soil impact berm due to penetration of the projectiles during range use;
- Soil erosion, resulting in burial of contaminated soils; or

- In areas with more extreme environmental conditions (i.e., wetter climate, lower pH soils, etc.), subsurface migration of contaminants due to infiltration of precipitation, and dissolution and transport of metal contaminants in groundwater.

Recommended practices for subsurface soil sampling include the following:

Subsurface Sampling Techniques for Small Arms Ranges:

- Truck-mounted sampling rig (i.e., Geoprobe®) or drill rig
- Hand Auguring
- Backhoe

A truck-mounted sampling rig such as the Geoprobe® system, which is a hydraulically powered percussion/probing machine used to advance sampling tools through unconsolidated soils, is a useful device for subsurface sampling. This system provides for the rapid collection of soil samples at shallow depths while minimizing the generation of investigation-derived wastes (IDW). To collect a soil sample, the 2-inch outside-diameter (OD) probe-drive sampler is pushed or driven to the desired sampling depth, the drive point is retracted (which opens the sampling barrel), and the sampler is pushed into the undisturbed soils. The soil cores are retained within stainless steel or clear acetate liners inside the sampling barrel.

Hand auguring typically can be used to collect soil samples from depths less than 10 feet bgs. Each hand-augered boring is advanced by manually turning the auger, which is equipped with 3-inch-diameter, cylindrical, stainless steel bits, until the auger bucket is filled with cuttings. The hand auger then is pulled from the boring and the cuttings are deposited on plastic sheeting or in a stainless steel mixing bowl for further sample handling. Hand auguring is continued until the desired sampling depth is achieved.

A **hollow-stem auger (HSA) drill rig** can be used for drilling to depths or in locations that are not accessible for a Geoprobe® rig or a hand auger due to soil conditions (e.g., gravels or hard formations). Soil samples are collected in continuous core samplers or hammer-driven sampling tubes (i.e., split spoons) that are used to retrieve samples of soil from the specified depth. One potential limitation with HSA rigs at firing-range sites is accessibility to locations along the impact berms; typically the side slopes and top surface of a berm are not accessible to vehicles such as conventional truck-mounted HSA rigs (this limitation would also apply to Geoprobe® rigs). Track mounted rigs can be used if site conditions warrant.

A **backhoe** is an effective means for collecting subsurface samples as well as representative bulk samples from the impact berm. Due to expected heterogeneity of bullet fragments and subsurface contamination within the berm, a backhoe may be the preferred equipment for collecting subsurface soil samples. In addition to sampling,

excavating with a backhoe can provide important information on the structural configuration and composition of the impact berm and surrounding soil types that may not be as easily obtained with drilling equipment.

Sampling Tip:

Give serious consideration to the use of a backhoe for soil sampling at a small-arms range site. The quality of data generally is better than that obtained using drilling or sampling rigs because:

- The samples are more representative, due to larger sample size; and
- Subsurface conditions (e.g., composition of impact berm) are more easily observed.

3.3.1.3 Field Sieving

Field-sieving of bullet fragments from soil samples is recommended to prevent including large bullet fragments in samples to be analyzed by the laboratory. Large bullet fragments (0.1 inch or larger) could significantly contribute to poor precision in the analytical data, because a pronounced "nugget effect" or unpredictably high metal concentrations would be expected if a fragment is included in the laboratory sample aliquot. To reduce this imprecision (which is inherent at small-arms range sites), removal of large metal fragments from discrete samples used for risk evaluation is recommended.

Field-Sieving of soil samples is a good idea, because it improves field precision by removing larger metal fragments. However, remember to record the amount of material discarded on the sieve!

Each soil sample that contains visible metal fragments target fragments, or bullets should be weighed, sieved, and re-weighed in the field. Sieving is performed to remove larger metal/target fragments that generally do not pose risk via the incidental ingestion exposure route (due to the large particle size), but which may significantly affect the precision of the analytical results. However, it is important to assess the quantity of metal/target debris removed from the sample in order to estimate the amount of these materials present at the site. These samples should be processed by passing the soil through a No. 10 mesh (2.0- millimeter [mm]) stainless steel sieve. The sieved fraction of soil should be placed in containers provided by the laboratory and submitted for analysis. The weights of the total soil sample and of the metal fragments retained on each sieve, if any, should be recorded in the field notes. Samples that do not require field-sieving can be placed directly into the appropriate sample containers.

3.3.2 Groundwater

Due to the limited mobility of lead, other metals, and PAHs in the subsurface environment, groundwater impacts (especially in the western US) may be minimal. However, collection of groundwater samples may be prudent at sites where the groundwater is relatively shallow (i.e., less than 15 feet bgs) and/or where the potential

for leaching is high (see Section 3.2). In addition, site-specific consideration of more mobile analytes besides metals and PAHs (i.e., solvents) may require the collection of groundwater samples.

Groundwater monitoring wells can be installed using a HSA rig, or using a truck-mounted sampling rig such as the Geoprobe® system to install temporary piezometers. The use of temporary piezometers or discrete groundwater sampling devices (such as a Hydrocone® or Hydropunch®) to collect samples for total metals analysis should be approached with caution, because these methods can result in the entrainment of significant quantities of aquifer sediment that may elevate the metals concentrations, even if there are no site impacts. Where acceptable to regulators, filtered (dissolved) metals analysis is recommended for a screening-level assessment of small-arms ranges with potential for groundwater contamination.

3.3.2.1 Well Purging

To ensure that a groundwater sample is representative of the water in the aquifer, the initial water present in the well must be removed. This removal process is called purging or evacuation and may be accomplished by bailing or pumping. Prior to purging, the stabilized water level should be measured, and total well depth measured or noted from previous measurements. From this information, the volume of water in the well can be determined so that a minimal purge volume can be calculated. During purging, measurements of pH, temperature, and electrical (or specific) conductivity should be taken initially and after removal of each borehole volume. Purging will continue until the pH, temperature, and electrical conductivity have stabilized on three successive readings and at least 3 casing volumes of water have been removed from the well; or until 6 casing volumes have been removed from the well (if parameter stabilization is not achieved); or until the well has been bailed dry. The stabilization range is typically ±0.1 unit for pH, ±1 degree Celsius (°C) for temperature, and ±5 percent for electrical conductivity.

3.3.2.2 Groundwater Sampling

Groundwater samples should be collected within 24 hours of completion of well purging. To the extent that such information is available, samples that are expected to be the least contaminated should be collected prior to those expected to be more contaminated to reduce the potential for cross-contamination between wells. Groundwater should be extracted from the monitoring wells using either a Teflon bailer, a persitaltic pump, or a submersible pump and tubing. All groundwater samples will be placed in prelabeled containers, and the container caps will be securely fastened.

Samples for dissolved metals should be filtered onsite using either a peristaltic pump and 0.45-micron filter assembly, or a barrel pump. Samples filtered using the peristaltic pump will be poured from the bailer into a clean, temporary sample container, then pumped through the filter assembly into clean sample containers. Samples filtered using the barrel pump will be poured directly into the decontaminated pump barrel and pumped through the filter into clean sample containers. The sample containers will be securely sealed, labeled, and preserved in accordance with the requirements for the requested analysis.

All sampling equipment which will contact the groundwater or samples, such as bailers, bailer attachments, pumps, filter assemblies, and pump tubing, should be decontaminated before and after use.

3.3.3 Surface Water and Sediment

Analysis of surface water and sediment samples also may be required to assess potential impacts to these media at sites located near surface water bodies, such as creeks, ponds, lakes, or estuaries. Sediment samples can be collected from accessible locations using a decontaminated shovel, trowel, or hand auger. Deeper sediment samples may require the use of a boat and/or long-reach sampling devices for collection. Surface water samples generally can be collected by submerging a decontaminated sample bottle (without preservative) in the water and allowing it to fill. In flowing streams, surface water and sediment sampling should include both downstream and upstream locations to determine the potential impact of a specific site.

3.4 ANALYTICAL CONSIDERATIONS

Both laboratory analysis and field analysis can be utilized to collect the data required for risk-based evaluation and focused feasibility study of a small-arms site. The recommended analytical parameters were presented in Table 3.1. The following discussion provides additional detail of the recommended analyses.

Analyses described in this section include:

- Field Analyses (X-Ray Fluorescence)
- Fixed-Based Laboratory Analyses
- Specialized Analyses (*In Vitro* Bioavailability and Lead Speciation)

3.4.1 Field Screening for Lead

Field analyses of lead in firing-range soils using X-ray fluorescence (XRF) was used for site characterization at two of the four risk-based demonstration sites. XRF is an established method for providing rapid measurement of metals (i.e., real-time results) with minimal sample preparation. It is based on measuring the X-rays emitted from the elements in a sample upon irradiation with higher-energy X-rays (either from an X-ray tube or radioactive source). While XRF can provide useful data under very short time frames, the use of this tool cannot be recommended in all cases for characterization of firing range sites because of the additional expense in comparison to fix-based laboratory costs, and because of potential uncertainties in the use of the data for risk assessment. Following is a discussion or the use of XRF for the risk-based demonstration project.

Co-location of fixed-based laboratory samples with a minimum of 10 percent of the field XRF samples is required to meet USEPA (1993a) requirements for screening data with definitive confirmation. To better ensure that XRF data correlate well with the fixed-base laboratory data, and to better support the risk analyses (Section 4), it is recommended that 20 percent of the XRF field samples be confirmed with laboratory

analysis. This approach was used for the risk-based initiative and provided added assurance of the usability of the XRF data for risk assessment.

Linear-regression analyses demonstrated that the XRF spectrometry data for the small-arms range in California (see Table 3.1) correlated well with the fixed-base laboratory lead data obtained using USEPA Method SW6010B. An R^2 value of 0.86 indicated a strong relationship between the fixed-base laboratory data and the XRF spectrometry data. Given the strong correlation, it was deemed acceptable to combine the XRF and laboratory lead data for use in the risk analyses. For the small-arms range in Alaska (Table 3.1), XRF results typically yielded higher values than the corresponding Method SW6010B results. However, because most of the lead concentrations at the Alaska site were low (50 mg/kg or less), these results may not be an appropriate indication of the usefulness of XRF screening at more contaminated firing-range sites. Another study determined an R^2 value of 0.83 for mobile laboratory bench-top XRF and fixed-base laboratory graphite furnace/atomic absorption spectrum (GFAAS) data for 72 samples, indicating a fairly good correlation of XRF and GFAAS results (Schneider *et al.*, 1994). These XRF results were expected to be biased low for samples with high lead concentrations due to matrix effects. As the absorption of fluoresced X-rays increased with the lead concentration, the low bias increased.

In summary, field XRF analysis can provide metals data with nearly real-time reporting, which can be useful in situations where the overall distribution of contaminant is unclear, or where it is essential that the data collection be completed with a minimum of samples within one field sampling event. The correlation with laboratory data from previous projects indicate that XRF data can be used for risk assessment purposes; however, this correlation should be demonstrated on each site-specific application.

But How Much Does It Cost?

Generally, field XRF analysis can be expected to be somewhat more costly than fixed-based laboratory analysis for metals, and the analytical data quality for fixed-based analysis is generally higher. Typically the cost of XRF analysis is on the order of $1,000 to $2,000 per day (plus mobilization costs), with the field analyst's capacity of up to 30 or 40 samples per day. Therefore, unit rates per sample can range from $35 to $65, which is generally more costly than fixed-based analysis for lead in soils. In addition, there may be some logistical problems associated with transporting the active radioactive source within the XRF instrument in certain states. Therefore, the usefulness of near-real-time XRF data should be carefully considered during project scoping.

3.4.2 Fixed-Based Laboratory Analysis

Laboratory analyses for firing-range soil samples from USAF sites should be performed in accordance with the following:

- *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods,* SW-846 (USEPA, 1996a), and

The following USEPA methods from SW-846 are recommended:

- SW6010B (trace inductively coupled plasma [ICP]) for antimony, barium, copper, and zinc.
- SW6010B or SW7421 graphite furnace atomic absorption (GFAA) for lead.
- SW 1311/6010B TCLP for metals (especially lead).
- SW1312 SPLP for metals.

Total metals analysis should be used for site characterization and risk evaluation purposes. TCLP metals analysis should be used to determine appropriate remediation requirements for site soils (i.e., would excavated soil be considered hazardous waste). SPLP analysis can be used to assess the potential for leaching of contaminants from firing-range soils. Note that several states (including Texas and California) may require a similar leachability test for hazardous waste characterization other than TCLP.

The following ASTM methods also are recommended for a few representative soil samples:

- ASTM D2937 - bulk density.
- ASTM D422 - grain size.
- ASTM D2216 - moisture content.
- ASTM D854 - specific gravity.

The results of the ASTM analyses can be used for evaluating the fate and transport of metal constituents through the vadose zone and to assess potential threats to groundwater. These parameters also can be used to evaluate soil treatment technologies, such as stabilization and soil washing.

3.4.3 Specialized Analyses for Risk Assessment

Two specialized analytical methods used to obtain site-specific information regarding the bioavailability of lead in site soils are briefly described below and in more detail in Appendix C.

- *In Vitro* Method for Estimating the Bioavailability of Lead in Humans. An *in vitro* extraction technique for estimating the relative bioavailability of lead in the digestive tract has been developed at the University of Colorado (CU) in Boulder, in conjunction with researchers from USEPA Region 8. Other laboratories also may provide *in vitro* bioavailability analysis. This method is currently undergoing peer review for journal publication (Drexler *et al.*, submitted for publication), and can be used to evaluate the applicability of default values for relative bioavailability that are conventionally used in the USEPA's Integrated Exposure Biokinetic Uptake (IEUBK) model for determining soil action levels for lead.
- Lead Speciation Analysis by Electron Microprobe. Lead speciation analysis is conducted by using an electron microprobe, which is similar to a scanning electron microscope, but with a multiple-band X-ray detector for determining the elemental

composition of very small particles within a sample. This information can be used as supporting evidence for the bioavailability values of lead in soils determined using the *in vitro* testing technique.

Use of these relatively low-cost analytical methods is strongly recommended, given the direct correlation between the lead species present in site soils and the relative bioavailability of the lead.

Who Cares about Bioavailability and Lead Speciation?

Use of these analyses at the California demonstration site was ***very well received*** by USEPA. The information was valuable because it provides a quantitative assessment of the relative bioavailability of the forms of lead found at the site in comparison to forms of lead at other lead contaminated sites (i.e., mining sites, smelters, etc.). Because only a few samples need be analyzed using these methods at each site (six to eight samples for *in vitro* test, and at least three samples for lead speciation), the data provides site-specific information for risk assessment and risk management ***at relatively low cost.***

In vitro bioavailability testing provides a quantitative value for relative bioavailability that can be used as a replacement for the default value in EPA's biokinetic models, while lead speciation analysis provides qualitative evidence of the same based on lead species present. The use of these data may actually have comparatively little impact on the remedial action goals developed for a site, as opposed to using default values for bioavailability. However, there is likely to be a significant advantage realized in increased acceptance of the overall remedial approach with the regulators by using these scientifically valid measurement techniques for bioavailability.

3.4.4 Lead Particle Size in Soil

Bioavailability of metallic lead has been shown to decrease with increasing particle size (Barltrop and Meek, 1979). There also is evidence to suggest that smaller soil particles (e.g., <100-250 µm) are more likely to be incidentally ingested than larger particles because the particles adhere more readily to the skin (Duggan *et al.*, 1985; Bornshine, *et al.*, 1987; Driver *et al.*, 1989; Sheppard and Evenden, 1994; Duff and Kissel, 1996; and Kissel *et al.*, 1996a). Therefore, lead concentrations in soil particle size fractions of <2.0 mm (i.e., total soil fraction) were compared with lead in the <250 µm particle size fractions in order to determine which soil fraction contained the highest concentrations of lead (results are summarized in Appendix C).

Selected samples collected during the risk-based initiative were analyzed for total lead as well as lead in the soil fraction passing through the 60-mesh (250 µm) sieve. Sample preparation involved sieving the sample through a No. 60-mesh sieve at the laboratory. An aliquot of the sieved soil then was analyzed for lead per USEPA Method SW6010B. The results of these comparisons indicated no significant differences in lead concentrations in the two soil fractions. Therefore, for firing ranges with characteristics that are similar to these small-arms and skeet ranges, analyses of the <250 µm soil fraction may not be necessary (i.e., one may be able to assume that lead concentrations in the total soil fraction are equivalent to the concentrations expected in the <250 µm soil fraction). Therefore, laboratory sieving of firing range soil samples through a No. 60 mesh sieve is not recommended.

How Large is the Lead?

The particle size of lead in soil at small arms ranges can have a significant impact on the risk and remediation of these sites. For example, intact and unweathered bullets from a pistol range may pose insignificant risk because of low likelihood of ingestion, and also may be easily removed by passing the soil through a No. 4 mesh screen. However, more weathered bullet fragments or "smearing" of lead against soil at higher-powered rifle ranges may result in more significant quantities of lead in smaller particle sizes that are more easily ingested, and also may be more difficult to remove from the soil during remediation (see Figure 6.1). Depending on the size of the site, a treatability study is generally warranted to assess the distribution of lead particle sizes in contaminated soils (see Section 6.3).

3.5 ECOLOGICAL CHARACTERIZATION

For abandoned or closed ranges, ecological receptors could be the most significant risk-drivers at a site. Therefore, characterization of the site ecology should be included in the field program.

A site ecological characterization should be performed to identify habitat conditions and wildlife receptors for the ecological risk assessment. The ecological characterization should include an evaluation of existing environmental information and a site visit by a qualified scientist with an understanding of ecological risk assessment. The information to be collected during the site visit should include:

- Characterization of existing site cover types and dominant plant species;
- Identification of wildlife habitats;
- An assessment of exposure pathways and receptor exposure points; and
- Presence of any visible signs of environmental stress that could potentially be induced by hazardous materials.

The field scientist should record information and field observations in a field logbook, and document representative and unusual site conditions with color photographs. Biota samples (e.g., plant tissue or invertebrates for bioassay) need not be collected at this time.

Existing ecological characterization data (such as facility environmental assessments, as well as documents from regional or state agencies) should be reviewed in conjunction with the site visit. However, it is particularly important to identify the applicability of regional or local studies to the actual range site.

SECTION 4

RISK ASSESSMENT

USEPA's (1989a and 1997a) risk assessment process consists of four principal steps. Though the terminology differs between the human health and ecological paradigms, the steps in the two processes accomplish similar goals. The results of the risk assessment are considered, along with other information, during risk management, which is the decision-making step conducted by regulators and other stakeholders once the risk assessment is completed. Figure 4.1 diagrams the risk assessment/risk management process, and provides the standard terminology for human health and ecological assessments. Recommended SMDPs are indicated on Figure 4.1; additional SMDPs may be warranted based on site- or facility-specific considerations (e.g., integration of the subject firing-range site into facility-wide remediation or Base closure strategies).

This section reviews the general process for assessing potential risks at small-arms firing ranges where soil is the primary contaminated medium. This process is designed to be flexible to accommodate local regulatory guidelines and requirements, as well as installation-specific objectives and policies.

4.1 GENERAL RISK ASSESSMENT CONSIDERATIONS

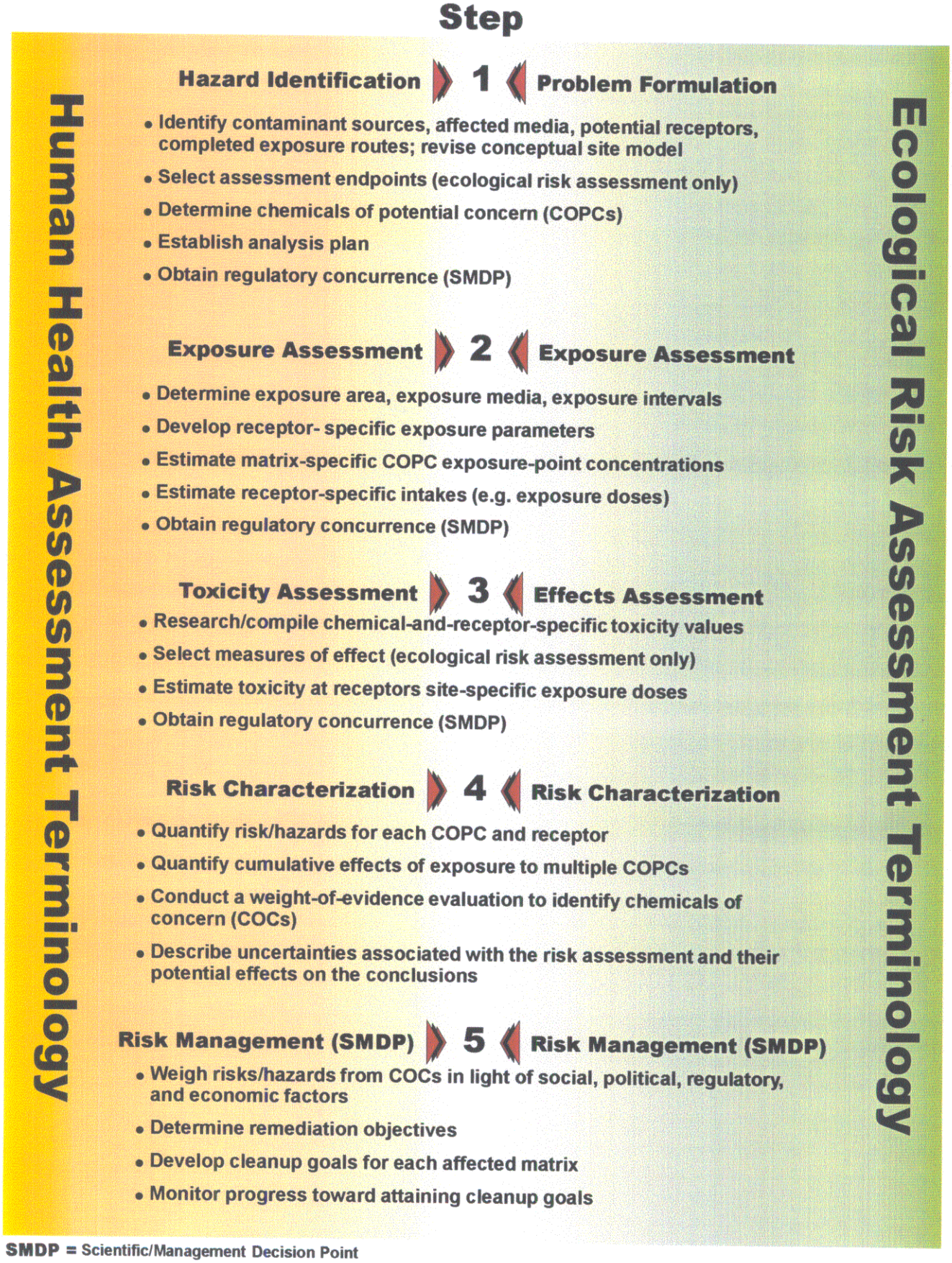
Interdependent risk assessments typically are conducted for human and ecological receptors that may be exposed to site-related chemicals in small-arms range soils. While differences in methods and assumptions justify separate analyses, several considerations are common to both types of risk assessment. These shared considerations are reviewed in this subsection and in Appendix A. The methodological considerations that are specific to human health and ecological risk assessments are reviewed in Sections 4.2 and 4.3 and in Appendices B and D. A deterministic approach to estimating risk (i.e., designed to produce a single risk value) is described in this protocol document. Widely approved and accepted guidance for conducting probabilistic risk assessments (i.e., designed to produce a range of risk values) is not yet available, and most states currently default to the more traditional deterministic approach to risk assessment.

4.1.1 Conceptual Exposure Models

As discussed in Section 3, preliminary CSM is used during scoping to identify data requirements and should be updated as new characterization data become available (Step 1 on Figure 4.1). The risk assessment should focus only on those receptors and exposure routes for which pathways are, or are likely to be, completed. Primary considerations for developing a CSM, and questions to be answered when updating the CSM and selecting the receptors to be evaluated in the risk assessment, are discussed in Appendix A.

FIGURE 4.1

STREAMLINED RISK ASSESSMENT PROCESS



SMDP = Scientific/Management Decision Point

Other objectives of Step 1 of the risk assessment process (Figure 4.1) are:

- Defining the receptor exposure area(s),
- Determining appropriate receptor exposure intervals in the soil column,
- Identifying site-related COPCs, and
- Estimating exposure-point concentrations for the COPCs.

Factors to consider while addressing these objectives are reviewed in the following subsections.

4.1.2 Determining Chemicals of Potential Concern

To complete Step 1 of the risk assessment process, soil analytical data must be evaluated to determine which contaminants are attributable to site activities, and which have the potential to pose a risk or hazard to receptors (i.e., which are COPCs). At most small-arms ranges, metals and PAHs are the primary COPCs, though the sources of these COPCs vary with the type of range. For example, PAHs are common COPCs for skeet ranges, but not at other types of small-arms ranges. For all contaminants targeted during the site characterization efforts (see Section 3.2), data quality and usability first must be reviewed to ensure that chemical data meet the project's data quality objectives (see Appendix A) and are of sufficient quality for use in risk assessment and remedial decision-making. The data review process is described in Appendix A.

Once usable data sets have been developed, identification of COPCs can involve:

- Frequency-of-detection screening to eliminate chemicals that are detected at low frequencies;
- Site-attribution analysis to confirm that contaminants are site related, and/or
- Toxicity screening to eliminate those contaminants with little or no potential to pose a threat to receptors.

Frequency-of-detection screening may be appropriate for PAHs and some metals in soils at small-arms range sites. Where permitted by the lead regulatory agency, chemicals detected in 5 percent or fewer of site soil samples from a given exposure interval may be dropped from further risk analysis. This screening technique requires analytical data for a minimum of 20 samples per exposure interval. A site-attribution analysis should be conducted for suspected metals contaminants detected in site soils. As described in Appendix A, site-attribution analysis involves statistically comparing site soil concentrations to those reported in background soil samples. Only those metals detected in site soils at concentrations that are significantly greater than background concentrations are considered to be site-related COPCs. Some states allow comparison of site PAH concentrations to background soil PAH concentrations as well, though more typically, all organic chemicals detected at firing-range sites are considered to be COPCs.

Chemicals detected at frequencies greater than 5 percent and determined to be site-related are carried forward for toxicity screening to determine final COPCs. (Note that USEPA recommends that the site-attribution analysis be conducted after the toxicity screening step. In such cases, all detected analytes are evaluated through toxicity screening.) Toxicity screening, often called a Tier 1 or screening-level analysis per regulatory guidance documents (e.g., USEPA, 1997a), involves comparing maximum detected concentrations of site-related contaminants to risk-based screening values. These screening values are considered to be safe concentrations at which adverse effects on receptors are not expected under chronic exposure scenarios (see Sections 4.2 and 4.3). Chemicals with maximum detected concentrations that exceed their respective toxicity screening values are considered the final COPCs, and are carried through the risk evaluation. Because toxicity screening criteria are different for human and ecological receptors, the final COPCs may be different for these classes of receptors. Note that some states (e.g., California) do not allow use of one or more of the above-listed screening methods to identify COPCs; in these jurisdictions, all detected target analytes may be considered COPCs. ***Use a SMDP to ensure regulatory concurrence with the proposed approach.***

COPC IDENTIFICATION – THINGS TO CONSIDER

- Is frequency-of-detection screening allowed? If so, were 20 or more samples collected?
- Have you identified your soil exposure intervals?
- Can a site-to-background comparison be conducted?
- Is a risk-based toxicity screening allowed?

4.1.3 Receptor Exposure Areas and Intervals

The receptor exposure area must be accurately defined, and may vary by the types of receptors (step 2 in Figure 4.1). The area within the firing-range site boundary (i.e., the IRP site or waste management unit boundary) typically is taken to represent the exposure area for human receptors, and often is appropriate for defining the exposure area for ecological receptors as well. However, if a significant portion of the site is developed or supports no vegetation, excluding these areas from the ecological receptor exposure area may be appropriate. Because IRP site boundaries may not always accurately reflect the area affected by site contaminants, site areas should be re-examined based on current sampling information. If necessary, the site boundary should be redrawn to include all contaminated areas, and to exclude uncontaminated areas. Alternately, receptor exposure areas that incorporate contaminated areas within which exposure pathways can be completed may be delineated independently of the IRP site boundary. The size and configuration of exposure area(s) must be clearly defined in the risk assessment report.

Based on the refined CSM (Appendix A), appropriate soil exposure intervals also must be defined for the receptors that could be exposed to soil contaminants. For example, nonintrusive human receptors such as groundskeepers or recreators, and surface-foraging wildlife receptors such as most birds, typically would be exposed only to contaminants in

the upper few inches of soil. Construction workers, burrowing wildlife, soil invertebrates, and plants (via their root systems) could be exposed to contaminants in surficial and deeper soils. Exposures via inhalation to contaminant particulates entrained in fugitive dust usually are evaluated based on surface soil concentrations.

It may be useful to define a surficial soil interval and a deeper soil interval to facilitate exposure estimates. For example, USEPA (1996b) suggests use of the upper 2 centimeters of soil as the surficial exposure interval. With regulatory concurrence, this interval may be redefined to include the upper 4 to 6 inches of soil to account for potential mixing of soils. It often can be difficult to accurately sample the upper 2 centimeters of soil and a slightly deeper surface soil sample may be acceptable. Depths of 10 to 12 feet are often adopted as the deeper exposure interval based on typical excavation depths for structural foundations and the limits of most root zones and animal burrowing depths. Exposure intervals should be determined on a case-by-case basis depending on site conditions (e.g., depth to groundwater or bedrock), anticipated receptors, current and future land use, and regulatory input. Whenever possible, propose and justify exposure intervals in the project work plan to ensure regulatory concurrence. In other words, ***use a SMDP to ensure regulatory concurrence with the proposed approach.***

4.1.4 Exposure Concentrations

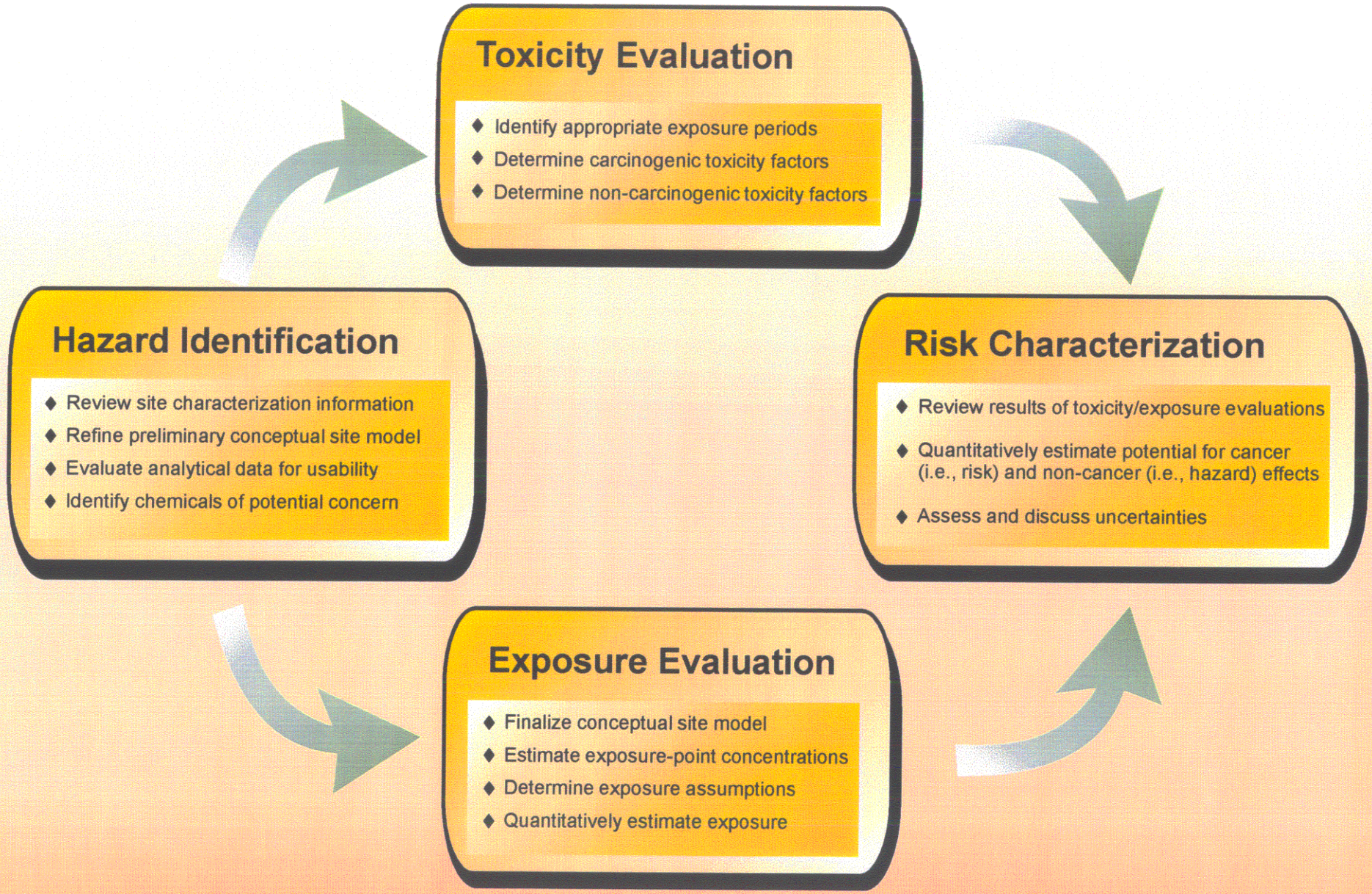
Once COPCs have been identified (Section 4.1.2), an exposure-point concentration must be developed for each for use in the exposure assessment component of the risk assessment (Figure 4.1). For screening-level risk analyses, such as those used to identify COPCs (Section 4.1.3), it is appropriate to use the maximum detected analyte concentration in the respective exposure intervals as the exposure concentration. For estimation of risks and hazards, however, USEPA (1992a) recommends using an average COPC concentration for the exposure area. The average is statistically determined based on the underlying distribution of the site COPC concentration data (i.e., normal, log-normal, or nonparametric). Soil concentrations also are used to model air and biota concentrations for use in exposure estimates. Recommended methods for determining COPC exposure-point concentrations are described in Appendix A. ***Use a SMDP to ensure regulatory concurrence with the proposed approach.*** The elements of human health and ecological risk assessment for small-arms firing-range sites are discussed in Sections 4.2 and 4.3.

4.2 HUMAN RISK ASSESSMENT

Human risk assessments (HRAs) are conducted to evaluate the potential risk/hazard to current and future human receptors from site-related contamination. Whether a site is slated for redevelopment for a new land use or for remediation to remove site-related contamination, the potential risk/hazard to current or future receptors can be determined using site-specific data and the HRA process outlined in Figure 4.2. The risk-based approach described in this protocol is consistent with the four-step risk assessment process defined by USEPA (1989a). A risk-based approach allows for the incorporation of site-specific data into the risk/hazard algorithms, providing more realistic estimates than those obtained using default input assumptions. A risk-based approach also is advantageous for sites where non-residential receptor scenarios are applicable and risk-based remediation goals that are reflective of these scenarios can be developed. Site-

FIGURE 4.2

HUMAN HEALTH RISK ASSESSMENT



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specific information, including information on particle size, lead speciation, and contaminant bioavailability is discussed in Section 3.5.3 and Appendix C.

The four-step HRA process is summarized in the following subsections. Risk assessment methods common to both human and ecological risk assessments have been discussed in Section 4.1 and Appendix A. Methods specific to the HRA are discussed below, with further details provided in Appendix B. Information on lead particle size, speciation, and bioavailability is provided in Appendix C.

4.2.1 Hazard Identification

Per USEPA (1989a), the hazard identification step involves collecting and reviewing all relevant site data and identifying COPCs (i.e., site-related chemicals with a potential to pose unacceptable risks/hazards to receptors).

What is Hazard Identification?

1. A review of site characterization information;
2. A refinement of the preliminary conceptual site model;
3. An evaluation of data usability; and
4. The identification of COPCs.

The collection and review of all site data, including a review of the physical characteristics of the site and the nature and extent of contamination, are performed during this step. As described in Section 4.1.2, COPCs are identified via a series of steps (e.g., frequency-of-detection, site-attribution analysis, and/or toxicity screening) to be agreed upon by site and regulatory representatives. The end result of the hazard identification step is a list of COPCs for each exposure interval. It should be noted that COPCs may differ by soil exposure interval because of potential differences in chemical concentrations with depth.

Site Data Review – Things To Consider

When evaluating historical data and/or data collected during the site characterization process, the following questions should be answered:

- What type of site-related contamination is present (e.g., metals, PAHs, lead shot, bullet fragments)?
- What is the lateral and vertical (depth) extent of contamination?
- Does the pattern of contamination mimic that described in the literature for small-arms ranges (e.g., expected area of impact; see Section 3)?
- What is the particle distribution of lead in site soils (large or small fraction)?
- What is the predominant soil type? Is contaminant mobility in the soil medium an issue? What is the depth to groundwater?
- Is there a nearby surface water drainage?
- Are there data gaps for the exposure intervals and chemicals to be evaluated?
- Have the data been validated for use in a risk assessment?

As discussed in Section 4.1.2 and Appendix A, frequency-of-detection and site-attribution analyses can be performed only if the data sets are statistically significant (i.e., if sample sizes are large enough). The toxicity screening step can be performed regardless of sample size. The maximum detected concentration for each chemical detected at the site is compared to a risk-based value that typically is equivalent to an individual cancer risk of 1E-06 for carcinogenic chemicals and hazard quotient (HQ) of 0.1 for noncarcinogenic chemicals. USEPA (1996b) states that carcinogenic risk-based values set at cancer risk levels of 1E-06 generally lead to acceptable cumulative risks between 1E-04 and 1E-06. Noncancer risk-based values set at HQs of 0.1 generally lead to acceptable cumulative hazard indices less than one. It is recommended (and a widely accepted practice) that for those chemicals with both carcinogenic and noncarcinogenic properties, the more conservative screening value be used in the toxicity screen. The toxicity screening values selected likely depend on state/regional preferences. Examples of commonly used screening values are: USEPA Region 9 (1999) preliminary remediation goals (PRGs), USEPA Region 3 (2000) risk-based concentrations (RBCs), state-specified Tier 1 values, or USEPA (1996b) soil screening values (SSLs). ***Use a SMDP to ensure regulatory concurrence with the proposed approach.***

Toxicity Screening Steps – Issues For Concurrence

Prior to performing the toxicity screening step, the following issues should be addressed:

- Is a risk-based toxicity screening allowed? If so, have you received regulatory concurrence on which toxicity screening values to use?
- How are nondetects to be treated? (refer to Appendix A for an example)
- Based on current and reasonably anticipated future receptors, what are the appropriate exposure pathways to be considered in the screening evaluation (e.g., direct contact with soil, soil-to-air pathway, soil-to-groundwater pathway, etc.)?

4.2.2 Exposure Evaluation

The objective of the exposure evaluation (Step 2 in the risk assessment process) is to estimate the type and magnitude of potential exposures by receptors to COPCs. The results of the exposure evaluation are combined with results from the toxicity evaluation (Step 3 on Figure 4.1) to characterize potential risks/hazards (Step 4).

What Is The Exposure Evaluation?

The key steps to successfully completing the exposure evaluation are:

1. Finalize and obtain concurrence of all regulatory officials on the conceptual site model;
2. Estimate exposure-point concentrations for each COPC and exposure interval;
3. Determine and receive concurrence of all regulatory officials on the exposure assumptions; and
4. Quantify exposure to COPCs.

Concurrence on the final CSM is a critical step in the risk assessment process. All decision-making parties should review and approve the site-specific receptors, exposure

pathways, exposure areas, media, and soil exposure intervals to be evaluated. Once the CSM is finalized, exposure-point concentrations for each COPC can be determined using the statistical approach described in Appendix A.

The exposure evaluation step also involves selecting, reviewing, and obtaining approval of the exposure models that will be used. For example, models or updates of models described in USEPA's (1989a) *Risk Assessment Guidance for Superfund* (RAGS) may be appropriate for non-lead COPCs. Models such as the USEPA (1996c) Technical Review Workgroups (TRW's) Adult Lead Model and the USEPA (1994c) IEUBK Model may be the preferred models for estimating potential risk to adult and child receptors exposed to lead in site soils. A detailed discussed of the recommended models is provided in Appendix B. ***Use a SMDP to ensure regulatory concurrence with the proposed exposure models.***

Is Lead a COPC? See Appendix B, Sections B.2.1 and B.2.2 for methods to predict blood lead levels in adult and child receptors.

Another key component of the exposure evaluation step is to define and receive concurrence on the exposure assumptions that will be used to quantify potential exposure and subsequent risks/hazards. A detailed discussion of exposure assumptions, commonly used USEPA references, and the justification/rationale for selection of exposure parameters is provided in Appendix B. The importance of obtaining regulatory concurrence cannot be overemphasized, particularly if site-specific exposure parameters are developed to accommodate the unique nature of a site and/or to best represent actual site conditions.

Are there non-lead COPCs? See Appendix B, Section B.2.3 to perform a exposure pathway evaluation.

4.2.3 Toxicity Evaluation

In order to evaluate the risks/hazards associated with potential exposure to COPCs at a small-arms range, the types of health effects and the quantitative relationship between the amount of exposure and the extent of potential effects must be identified. The objectives of the toxicity evaluation (Step 3 in the risk assessment process) are to weigh available toxicological evidence regarding the potential for a particular chemical(s) to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects.

What Is The Toxicity Evaluation?

The key steps to successfully completing the toxicity evaluation are:

1. Identify appropriate exposure periods for each receptor; and
2. Determine toxicity factors for carcinogenic and noncarcinogenic COPCs.

It is strongly recommended that a toxicologist or an individual familiar with toxicity factors perform this component of the HRA. The most widely used and accepted references for toxicity information include:

Lead

- The Agency for Toxic Substances and Disease Registry (ATSDR, 1993) *Toxicological Profile for Lead*; and
- Publications produced by the Centers for Disease Control (CDC), such as *Preventing Lead Poisoning in Young Children: A Statement by the Centers for Disease Control* (CDC, 1991).

Non-Lead COPCs

- The most current edition of USEPA's Integrated Risk Information System (IRIS) database, which is available on the USEPA's website;
- The most current edition of USEPA's Health Effects Assessment Summary Table (HEAST); and
- Provisional toxicity values developed by USEPA's National Center for Environmental Assessment (NCEA) and reported by USEPA regions (e.g., USEPA Region 9 PRG table, USEPA Region 3 RBC table), which can be found on regional websites.

See Appendix B, Section B.3 for a more detailed discussion of the toxicity evaluation step for COPCs.

4.2.4 Risk Characterization

The final step of the risk assessment process is the risk characterization step. The purpose of this step is to 1) review the results from the exposure and toxicity evaluation steps (i.e., steps 2 and 3 of the risk process); 2) quantitatively estimate the potential for cancer and noncancer effects; and 3) assess uncertainties associated with the risk assessment process (steps 1 through 4).

A thorough review of the results from the exposure and toxicity evaluation steps is recommended to provide a "reality check" for the steps leading up to the risk characterization step. The risk assessor is encouraged to review the results with respect to the site data to determine if the COPC concentrations correlate with the individual risk/hazard estimates for each contaminant. Once completed, the cancer (i.e., risk) and noncancer (i.e., hazard) estimates can be determined for each COPC having available toxicity factors. The cumulative estimates for risk and hazard also can be determined by summing across exposure pathways for each receptor evaluated.

See Appendix B, Section B.4 for a more detailed discussion on the risk characterization step.

Per USEPA (1992b), the uncertainties associated with the four risk assessment steps are documented and evaluated in the risk characterization step. Most regulatory agencies require at least a qualitative evaluation of uncertainties likely to significantly impact the quantitative estimates of risks/hazards. Factors such as the number of samples collected and analyzed, the availability of toxicity factors, the fate and transport of COPCs, and the receptor exposure assumptions are examples of uncertainties that may impact the quantitative risk/hazard results. These uncertainties should be clearly identified and the potential impacts (i.e., under- or overestimation of risk/hazard) on the quantitative results should be described.

4.3 ECOLOGICAL RISK ASSESSMENT

Due to noise and safety considerations, firing ranges typically are located in remote portions of Air Force facilities, well removed from populated areas (e.g., residential, commercial, industrial, recreational areas). Because range locations often are peripheral to high-activity, developed areas, these sites may be frequented by wildlife once range activities cease. Therefore, ecological risks may drive the need for remediation at abandoned or inactive small-arms firing ranges that have not been redeveloped (e.g., inactive ranges designated as open space or used for recreation). For this reason, it is particularly important to consider potential risks from exposures of ecological receptors to firing-range contaminants in soil in determining the need for remedial action.

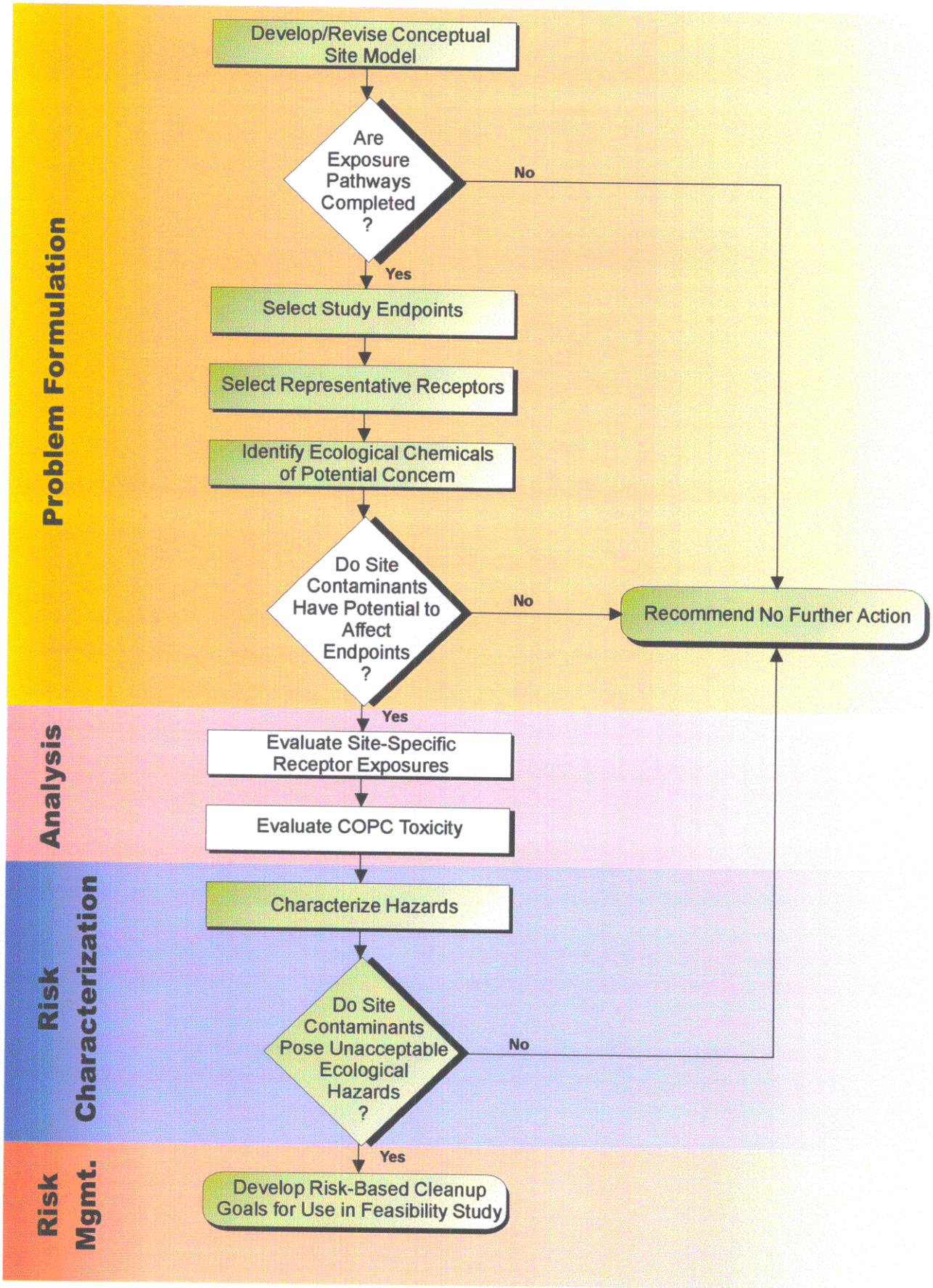
Because of the diverse species of non-domesticated plants and animals that may be exposed to soil COPCs at any given site, and because the body of toxicological information for ecological receptors is not as comprehensive as that developed for humans, the available guidance for performing ecological risk assessments (ERAs) is less specific than available HRA guidance. Recent USEPA (1997a and 1998a) guidance provides a helpful framework for conducting ERAs, and some states also have published or are developing ERA guidelines or regulations.

Many of the considerations addressed in the HRA also are components of the ERA (refer to Figure 4.1). However, there is a key difference in the objectives of the two risk assessment paradigms: HRAs are designed to be protective of individuals of a single species (*Homo sapiens*), including members of sensitive subpopulations, while ERAs typically are designed to be protective of populations of multiple species in order to ensure that ecosystem functions are not adversely affected. Exceptions to the "population- or community-level" focus of ERAs occur when species of plants or animals that are considered threatened or endangered are potentially at risk. In these cases, protection of the individual organism to ensure the genetic viability of the species becomes an objective of the ERA. Such site-specific study objectives are referred to as "assessment endpoints" in ERAs (USEPA, 1997a and 1998a).

An expanded diagram of the ERA process is provided on Figure 4.3. Although the figure depicts the ERA process as linear, often the process is iterative, with some steps being revisited as new data become available. For example, USEPA (1997a) describes an

FIGURE 4.3

ECOLOGICAL RISK ASSESSMENT PROCESS



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eight-step process, with screening-level problem formulation and analysis steps, followed by the same steps (plus risk characterization) with refinements based on the results of the screening-level effort. The objectives of the steps in the ERA process as they apply to contaminated soils at small-arms firing-range sites are briefly summarized in the following subsections. Additional details on the application of ERA methods to firing-range sites, based on lessons learned at the four demonstration sites, are provided in Appendix D.

4.3.1 Problem Formulation

The key elements of problem formulation are summarized on Figure 4.3. Based on the results of research through federal, state, and installation natural resource records, a site-specific ecological characterization, and land use, the CSM is used to summarize exposure hypotheses for the ecosystem potentially at risk. Early in the project, an ecologist or biologist should visit the site to identify habitat conditions, assess the types of wildlife (including sensitive species) that may be present, and to determine the media to which they may be exposed (se Section 3.6). Due to limitations on the types and quality of toxicological data available for wildlife receptors, hazards from soil contaminants are quantified only for the ingestion exposure route; hazards from dermal contact and inhalation exposures typically are acknowledged as generally unquantifiable in the uncertainty discussion (Section 4.3.3).

The preliminary ecological COPCs are determined based on site history, a site-attribution analysis, and the affected media. Metals as fines in soil are the typical contaminants at rifle (and pistol) range sites (see Section 3.2). Evidence from the three rifle-range demonstrations sites evaluated during preparation of this protocol indicated that spent shell casings and bullet fragments pose little direct hazard to terrestrial ecological receptors (i.e., they are too large to be absorbed by plants or ingested by wildlife). The fines are more likely to be incidentally ingested along with soil particles by foraging or nesting/burrowing wildlife. The fines also are more likely to leach into underlying soils, where soluble metals and PAHs may become available for plant and invertebrate uptake.

Sieving of soils at the three rifle-range demonstration sites generally suggests that the concentrations of lead in the soil are comparable in the smaller-grain-size fraction (<250 μm), and the larger-grain-size fraction of total soil (<2mm). Conversely, at the skeet-range demonstration site, lead was present in the form of shotgun pellets. While lead shot is not directly available for plant or invertebrate uptake, and is unlikely to be incidentally ingested by most wildlife, shot can pose a unique hazard to certain animals in upland terrestrial ecosystems. Granivorous birds (e.g., dove, quail, grouse) selectively ingest grit, which is retained in the crop or gizzard to aid in the mechanical breakdown of seeds as part of the digestive process. Because lead shotgun pellets may be of a size that mimics non-anthropogenic grit (e.g., gravel), shot may be selectively ingested by these birds. Therefore, this exposure route should be considered when selecting assessment endpoints and receptors for former skeet- or trap-shooting range sites.

Based on the assessment endpoints selected for a site, ecological receptors representative of the ecosystem(s) at and near the site should be selected for evaluation. Because of the diversity of potential ecological receptors at any given site, members of

the predominant trophic levels are selected for evaluation, and are assumed to be representative of other species at the site. It is helpful to construct a simple food web diagram of the site ecosystem to aid in identification of appropriate receptors. Example assessment endpoints are listed in the text box below, and an example terrestrial food web is provided in Appendix D.

Example Firing-Range Assessment Endpoints

- Protection of omnivorous, ground-feeding birds from reproductive or growth impairment caused by lead in soil
- Maintenance of the meadow ecosystem, with no unacceptable population-level effects or community alterations, due to the presence of site-related lead

The problem formulation process should be revisited once site characterization data have been collected and evaluated, and the CSM has been revised. Assessment endpoints may need to be refined to reflect particular COPCs and species at risk, or other site-specific conditions. Regulatory concurrence on the items listed in the following text box should be sought during the problem-formulation step. Such periodic consultation with regulators is strongly encouraged, as indicated by the SMDPs shown on Figure 4.3..

Problem Formulation SMDP

Seek regulatory concurrence on:

- Ecosystem(s) at risk
- Methods for identifying COPCs (chemical stressors)
- Proposed assessment endpoints
- Receptors proposed for evaluation
- Exposure/effects analysis plan

4.3.2 Analysis

Once the screening-level problem formulation step is completed, the preliminary list of ecological COPCs can be refined in a screening-level analysis step, as described in Section 4.1.2 (USEPA, 1997a), or part of Tier 1 in many state guidance documents. The screening-level analysis step relates conservative exposure doses or concentrations to safe concentrations of a given chemical. Chemical- and receptor-specific toxicity screening values typically are literature-based no-observed-adverse-effect levels (NOAELs) for wildlife, and no-observed-effect concentrations (NOECs) for plants and invertebrates in direct contact with affected soils. Soil benchmarks based on these toxicity endpoints also are available for selected chemicals and receptor groups (e.g., Neuhauser *et al.*, 1985; Will and Suter, 1995a and 1995b; Sample *et al.*, 1996). If the benchmark screening approach is used, maximum site soil concentrations of target analytes are compared directly to the appropriate soil benchmarks.

If no final COPCs are identified, a recommendation for no further action (NFA) can be made for the site (based on ecological considerations). Identification of a COPC for further evaluation warrants completion of another iteration of the analysis and risk characterization steps of the ERA (Figure 4.3).

If an HQ approach is used for toxicity screening, a screening-level HQ (SLHQ) is developed for each representative receptor and preliminary COPC, using conservative exposure assumptions and toxicity reference values (TRVs) intended to be protective of the ecosystem at risk. The HQ is the ratio of the site-specific exposure dose or concentration to the dose or concentration that is expected to induce no adverse effect in the receptor (i.e., the TRV). SLHQs for chemicals with similar mechanisms of toxicity (e.g., PAHs) should be summed to develop a screening-level hazard index (SLHI) to account for potential additive effects from exposure to multiple chemicals. HQs or hazard indices (HIs) greater than unity are assumed to reflect a potential for the COPC(s) to cause an adverse effect on an assessment endpoint (USEPA, 1997a and 1998a). Therefore, if a chemical's SLHQ (or a group of chemicals' SLHI) is greater than 1 for a given receptor, the chemical should be retained as final a COPC for further evaluation in the ERA.

Screening-Level Hazard Quotients and Hazard Indices

$$\textbf{SLHQ} = \frac{\text{Screening-level exposure dose or concentration}}{\text{No-adverse-effect toxicity reference value}}$$

$$\textbf{SLHI} = SLHQ_{C1} + SLHQ_{C2} + \ldots . SLHQ_{Ci}$$

Where: C = soil COPCs (1 through *i*) with similar modes of action

The analysis step of the ERA consists of the exposure assessment and the toxicity, or effects, assessment (Figure 4.4). The exposure assessment involves estimating exposure doses for the representative wildlife receptors using receptor- and site-specific information (see Appendix D). The exposure dose includes intakes of a COPC through ingestion of soil, contaminated plant matter, contaminated prey, and (where appropriate) contaminated drinking water. Contaminant concentrations in biota consumed by the representative receptors are modeled using soil exposure-point concentrations in conjunction with plant uptake factors (PUFs) and animal bioaccumulation factors (BAFs). PUFs and BAFs may either be derived from literature sources, or may be developed using site-specific bioassay and/or chemical-specific bioavailability data. *In vitro* lead bioavailability data collected at firing-range sites during development of this protocol were used to derive site-specific lead BAFs for selected mammalian receptors, and to adjust site-specific bioavailability assumptions in the exposure dose algorithms (see Appendices C and D). In the absence of bioassay data, literature PUFs and BAFs are applied to the soil exposure-point concentrations (Section 4.1.4) to estimate potential risks to plants and invertebrates.

The effects assessment evaluates the potential for site COPC concentrations to have a toxic effect on the representative receptors at the assessment endpoints. Measures of effect (i.e., measurement endpoints) are researched or developed from the toxicological literature (Appendix D). If no special-concern species are at risk at the site, the lowest-observed-adverse-effect level (LOAEL) or lowest-observed-effect concentration (LOEC) may be suitable measurement endpoints. If risk at the individual-organism level is of concern, NOAELs and NOECs are more appropriate measures of effect. ***Measurement endpoints should be selected in collaboration with regulators (SMDP).***

A third iteration of the analysis phase of the ERA may include site-specific validation sampling and analysis to verify conclusions based on soil data and literature toxicity information. Validation sampling may include conducting toxicity testing of soil samples from the site to establish uptake of COPCs in plants and/or invertebrates, conducting quantitative wildlife studies, or collecting biological tissue samples for analysis to better quantify bioavailability and bioaccumulation of COPCs and their impacts through the food web. General methods for field validation studies are described in USEPA (1989b and 1992b) and state guidance documents.

Analysis SMDP

Seek regulatory concurrence on:

- Exposure dose algorithms
- Measures of effect
- PUF and BAFS
- Validation study methods

4.3.3 Risk Characterization

Risk characterization consists of two elements: risk estimation and risk description. Risk estimation relates the site specific exposure dose to the measure of effect in the form of an HQ for each COPC and receptor. The measures of effect (e.g., NOAELs or LOAELs) used to characterize potential hazards at a firing-range site should be selected with regulatory input (see above text box). To account for potential additive effects from exposure to multiple chemicals, calculation of HIs by summing the HQs for chemicals with similar modes of action or target organs also may be warranted. Typically, an HQ or HI of 1 is interpreted as an indication of the potential for risk. However, even for COPCs with HQs greater than 1, the weight of evidence may lead to a conclusion that the chemical is not of ecological concern.

Examination of the weight of evidence is part of the risk description, where influencing factors such as the magnitude of the HQs and their relevance to the assessment endpoints are evaluated (USEPA, 1998). Uncertainties inherent in the ERA methods and assumptions, and their potential effect on the results of the assessment, also are examined. In most states and USEPA regions, qualitative uncertainty analyses are acceptable. Chemicals of concern (COCs) are determined based on the results of the risk characterization step of the ERA. If no COCs are identified, NFA can be recommended. If COCs that threaten the assessment endpoints are identified, a validation study may be recommended to confirm the results of the ERA, and/or the site may be recommended for remediation. If a validation study is conducted, revised HQs should be calculated using refined exposure doses developed using the results of the validation sampling. If remediation is warranted, an FFS (Section 5) is required, and risk-based cleanup goals for the ecological COCs must be developed. The final determination of the need for site remediation and the final cleanup goals is made during the risk management process (see Figure 4.1 and Section 4.4).

Risk Characterization SMDP

Seek regulatory concurrence on:

- Application of hazard indices (HIs)
- Validation study scoping
- The need for/type of validation study
- The significance of the HQs/HIs

SECTION 5

DEVELOPING RISK-BASED CLEANUP LEVELS FOR SOIL

Once the HRA and ERA steps have been completed and COCs (i.e., chemicals of concern) have been determined for the receptors evaluated, the next step in the risk-based approach to small-arms range remediation is the determination of cleanup levels. As previously stated, if there are no COCs for either human or ecological receptors, the remainder of the steps outlined in the protocol document (including the determination of cleanup levels) are not required. Under this simplified scenario, the site closure process is expedited by pursuing NFA with the appropriate regulatory agencies. However, if COCs were identified during the risk evaluations, health-protective remediation goals should be determined for the site. These remediation goals ultimately are used by risk managers and decision-makers to determine cleanup/action levels for the remedial alternative(s).

The following sections describe the process to determine risk-based remediation goals for human health and ecological COCs using a risk-based approach. The determination of site-specific cleanup/action levels using these risk-based remediation goals also is described. It should be noted that the approach presented is focused on soils because soils are the medium likely to require remediation at most firing-range sites.

5.1 OVERVIEW OF SOIL CLEANUP LEVELS

The purpose of deriving chemical-specific risk-based remediation goals is to assist the risk managers in determining the appropriate final cleanup levels that will be protective of human health and the environment at the site. The remediation goals are designed to be protective of the receptors evaluated per the final site CSM, and of other resources that may be impacted by site-related contaminants (e.g., groundwater, surface water, and potentially sensitive habitats).

5.1.1 Numerical Risk-Based Remediation Goals

In most cases, numerical site-specific risk-based remediation goals can be estimated by performing a "reverse" risk calculation (i.e., input the numerical equivalent of the what is determined to be "acceptable risk" into a risk algorithm to compute the contaminant concentration in soil that equates to that level of risk). This approach is commonly used when determining PRGs and can be used to determine a range of acceptable risk levels from which risk managers and decision-makers can select the final cleanup goals. The risk algorithms used should be identical to those used in the human health and ecological risk assessments for the exposure routes evaluated. See Appendix B for an example "reverse" calculation for lead.

Examples of Numerical Risk-Based Remediation Goals [a/]

Site Location	Antimony	Copper	Lead	Zinc
California (open space/industrial scenario)	6	250	1,000	NA [b/]
Texas (open space/residential scenario)	25	250	500 [c/]	1,000

[a/] All values in mg/kg.
[b/] Zinc was not retained as a COC at this site.
[c/] This value is the default Texas Natural Resource Conservation Commission (TNRCC, 1998) human health risk-reduction standard No. 2 for a residential scenario

5.1.2 Non-Numerical Risk-Based Remediation Goals

Another consideration when determining goals is non-numerical factors that may drive a site cleanup. Pre-defined remedial actions or cleanup objectives may preclude the need to determine numerical standards. For example, if regulators require that a site be remediated until the source of contamination is removed, numerical cleanup goals may not be necessary. Rather, the criteria to determine when the source has been sufficiently removed to satisfy the remediation criteria must be defined instead. These also may be circumstances when source materials (e.g., lead shot) pose a specific hazard independent of contaminant concentrations in site soils.

Examples of Non-Numerical Risk-Based Remediation Goals for a Skeet Range:

Target Material	COC	Ecological Risk-Based Remediation Goal
Shotgun Pellets	Lead	Remediate surface soil interval to the extent practicable using best available technology
Skeet Range Target Fragments	PAHs	Prevent game bird exposure to fragments of skeet targets > 2 millimeters and 3 inches in diameter to the extent practicable using best available technology

5.1.3 State and Federal Action Levels

The final consideration when determining goals is to evaluate existing state and/or federal requirements. Health-based cleanup criteria (e.g., TNRCC's Risk-Reduction Standards or USEPA's action level for lead in soils) and non-health-based cleanup criteria (e.g., technology-driven standards and ARARs) should be evaluated. Depending on the receptors evaluated and the regulatory framework for the site, published values (e.g., PRGs or SSLs) may be required rather than a site-specific goal for a COC. For example, if a residential scenario is evaluated and lead is a COC, many regulatory agencies will require the use of the USEPA (1994a) 400-ppm action level to be protective of a residential receptor. Evaluation of residential exposure is the most conservative

scenario because: 1) children absorb more ingested lead per kilogram body weight compared with adults; and 2) children are more sensitive to the toxic effects of lead compared with adults. Therefore, the residential action level for lead (based on exposure to children) is substantially lower than action levels protective of adult industrial exposures.

Currently, there are no non-occupational federal health-based standards for lead in soil. However, USEPA has issued the following guidance for soil screening levels:

- *Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities* (USEPA, 1994a);
- *Guidance on Residential Lead-Based Paint, Lead-Contaminated Dust, and Lead-Contaminated Soil* (USEPA, 1994b); and
- *Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil* (USEPA, 1996c).

USEPA's guidance for lead at CERCLA and RCRA sites establishes 400 ppm as a recommended risk screening level for lead in soil for residential land use. This residential screening level for lead in soil was calculated using USEPA's (1994c) IEUBK model and residentially based default exposure parameters for children. Numerical cleanup standards also can be developed using the IEUBK model on a site-specific basis, where site data support modification of the model default parameters, including numerical factors for the bioavailability of lead at the site (see Appendix B).

USEPA's Soil Screening Level for Lead (residential land use): 400 ppm
USEPA Drinking Water Action Level for Lead: 15 µg/L

For nonresidential, occupational exposure, USEPA (1996c) has developed a method for assessing human health risk from lead in soils based on fetal blood lead concentrations in a pregnant woman (i.e., a pregnant woman exposed to lead-bearing soil in an occupational setting). The method's algorithms can be used to calculate protective soil lead concentrations using site-specific input parameters; however, the guidance stops short of recommending specific screening levels for the nonresidential scenario. It is believed that most of the Air Force small-arms firing-range sites will fall under a future industrial or open space land use scenario, rather than a residential scenario. Therefore, the use of the USEPA's (1996c) TRW Adult Lead Model is likely to be more appropriate, whereas use of the IEUBK model (USEPA, 1994c) would be more conservative and would result in more stringent cleanup goals.

5.2 SELECTING THE APPROPRIATE CLEANUP LEVEL

Human health and ecological risk assessors will perform interdependent evaluations to determine numerical and non-numerical remediation goals and state/federal action levels for the COCs identified during the HRA and ERA. This evaluation may involve the quantitative calculation of goals, researching non-numerical goals, and researching more

generic, chemical-specific cleanup criteria. Prior to performing this step, a hierarchy should be developed to determine how value(s) will be weighted/ranked in the decision-making process.

Once a complete suite of human health and/or ecological remediation goals is developed (as described in Section 5.1), the hierarchy should be used to determine cleanup goals for each COC. A summary of cleanup goals should be presented in tabular format to aid in the decision-making process. If a COC is common to both human health and ecological receptors, ***a SMDP is recommended to determine which value should be selected as the COC remediation goal.***

Potential soil-to-groundwater impacts may also be considered during the determination of cleanup goals. However, based on the generally low mobility of metal contaminants associated with firing range sites, soil cleanup levels based on potential soil-to-groundwater impacts (discussed in Section 3.2) are not expected to be more restrictive than human health- or ecological-based remediation goals.

The outcome of this step should be one cleanup level (i.e., concentration) for each human health and/or ecological COC identified during the risk assessment process. These cleanup levels then can be used to determine soil volumes that require remediation during the FFS component of the risk-based approach.

Selecting Cleanup Levels

1. Can risk-based remediation goals be back-calculated?
2. Are there pre-existing cleanup criteria for the site?
3. Do any of the COCs have state or federal cleanup criteria such as soil screening levels or risk-based values?
4. Is a current or future residential scenario evaluated?
5. Are human health or ecological receptors considered to be the "risk drivers" at this site?
6. What is the approved decision-making hierarchy to select a cleanup level?

SECTION 6

FOCUSED FEASIBILITY STUDY

Remedial actions at firing-range sites may be warranted to mitigate risks to human and/or ecological receptors due to the presence of soil contaminants such as lead. Because small-arms firing ranges typically are characterized by discrete areas with relatively high soil lead concentrations (especially within the impact berm areas), it is anticipated that most ranges will require some measure of remediation to demonstrate an acceptable risk under reasonably anticipated future land use scenarios. If site-related contaminants (COCs) pose an unacceptable risk, then a FFS (focused feasibility study) is needed to evaluate remedial alternatives to reduce these risks. This FFS should be performed in accordance with USEPA (1988) guidance as well as applicable state regulations and requirements. However, instead of a fully developed CERCLA FS, a focused evaluation of alternatives is justified based on the limited number of viable alternatives for small-arms firing-range sites.

What is a Focused Feasibility Study?

A focused FS is defined as an expedited feasibility study that considers an appropriate but limited number of relevant technologies and alternatives. This is in contrast to a fully developed CERCLA FS, which could consider the full universe of technologies and alternatives. The FFS is justified based on the more limited scope of remediation required at a small arms range in contrast to a more complex CERCLA site.

Components of the FFS should include:

- Development of remedial action objectives (see Section 6.1.1);
- Determination of the volume of contaminated media (Section 6.1.2)
- Screening of a limited number of appropriate technologies (Section 6.2);
- Treatability studies, as appropriate (Section 6.3);
- Development of up to 5 remedial alternatives (development of a greater number of alternatives followed by alternative screening is not recommended); and
- Detailed analysis of the alternatives, with recommendations of a preferred alternative.

6.1 APPROACH AND OBJECTIVES

A description of the general approach and objectives for remediation of site soils is required prior to implementation of the FFS. This information provides the basis for evaluation of remedial alternatives.

6.1.1 Remedial Action Objectives

Remedial action objectives (RAOs) are developed to evaluate the applicability of remedial technologies and the effectiveness of remedial alternatives. These objectives consist of matrix-specific goals for protecting human health and the environment and for meeting ARARs or risk-based cleanup goals to the extent practicable in a cost-effective manner. RAOs are based on site-specific information, including the nature and extent of site constituents, human and ecological risk assessment results, existing site conditions, and future land use plans. RAOs typically focus on controlling exposure of receptors to COCs via exposure routes evaluated in the BRA (see Section 4), and on controlling any further release of hazardous substances into the environment.

RAOs are statements that define the extent to which a site requires remediation to meet the NCP objectives of protecting human health and the environment. RAOs reflect the COCs, exposure routes and receptors, and acceptable contaminant concentrations for each affected medium. Once developed, RAOs can be numerically expressed as preliminary cleanup goals, or COC concentrations that achieve the matrix-specific levels of protection specified by the RAOs.

Example RAOs:

- Protection of sensitive human receptors from risks and hazards associated with excess exposure (ingestion, inhalation or dermal contact) to metals in soils.
- Protection of site ecological receptors (such as terrestrial organisms) at the population level from risks associated with ingestion of metals.
- Protection of shallow groundwater from vertical migration from contaminated soils.

6.1.2 Volume of Contaminated Soil

Determination of the volume of contaminated soils is required prior to evaluating remedial technologies and alternatives in the FFS. The affected volume of soil requiring remediation can vary from a few hundred cubic yards at small sites, to more than 20,000 cubic yards at larger sites or multiple ranges. The volume of soil requiring remediation will have a significant impact on the estimated cost of remediation, as well as the technologies that might be most cost-effectively applied. For instance, offsite disposal would likely be more attractive in comparison with onsite treatment for a relatively small volume of soil, while larger volumes would be cost-prohibitive to transport offsite for disposal.

Upon development of cleanup goals for the site (Section 5), determination of the volume of soil requiring remediation can be made by comparing the distribution of site COC concentrations that exceed the action levels. A remedial approach should be developed that results in residual site COC concentrations that are, *on average,* below the risk-based remediation goal. This approach will minimize the soil volume requiring remediation, while still being fully protective of human health and the environment. This approach is consistent with the BRA, which estimates potential risks to receptors using exposure-point concentrations based on the arithmetic mean (e.g., 95-percent upper confidence limit). The calculation of the soil volume requiring remediation involves simulating remediation using existing site data to calculate the volume required to reduce the residual COC exposure-point concentration at the site below the risk-based cleanup

goal. A detailed explanation of this "virtual remediation" approach is provided in Appendix E.

6.2 REMEDIAL TECHNOLOGIES

A wide range of remediation technologies are potentially applicable to contaminated soils at firing-range sites, as described in this section. Site characteristics that can significantly impact the selection of remedial technologies for a site include the following:

- **Munitions Characteristics:** Rifle, pistol, and shotgun munitions will impact site media (i.e., soils) in different degrees with respect to the nature and extent of metals contamination in site soils.

- **Soil Characteristics:** The soil type can impact the particle size distribution of lead and other metals in soils. Also, soils with a high clay content may have a higher proportion of sorbed lead than sandy soils, which could impact the leachability of lead from soils.

- **Leaching of Metals:** Untreated site soils that exceed the TCLP hazardous waste criterion for lead will require more intensive materials management (i.e., as hazardous waste) if offsite disposal is considered. Soils that pose a risk to leaching contaminants to groundwater may require additional handling or treatment.

- **Lead Speciation:** Sites with a significant percentage of lead as metallic lead (i.e., not weathered into more soluble chemical species such as lead oxide or lead carbonate) will be more amenable to lead removal processes such as physical beneficiation due to the higher density of metallic lead species compared to weathered lead species.

- **Onsite Disposal Areas:** Disposal of contaminated site soils in an onsite disposal area (such as a Base landfill, or a corrective action management unit [CAMU]) can significantly reduce the cost of site restoration. Some Air Force bases have treated firing-range soils to render the soil nonhazardous (i.e., below the TCLP criteria) prior to onsite disposal.

- **Future Land Use:** The future use of the firing-range site can significantly impact the available technologies as well as the cost of remediation. For example, cleanup to residential standards may not be viable with onsite treatment options, while industrial standards may be more easily achieved. However, cleanup to industrial land use criteria may result in regulatory requirements for institutional controls (such as land use restrictions and monitoring) because contaminated materials are left in place.

A list of general response actions and available technologies for remediation of firing-range sites is provided in Table 6.1. These actions and technologies have been used at firing-range sites and/or are likely to be effective for firing-range sites. These technologies should be screened for site-specific conditions using the criteria of effectiveness, implementability, and cost. Retained technologies are used to assemble several remedial alternatives that meet the RAOs for the site (USEPA, 1988).

TABLE 6.1
SUMMARY OF GENERAL RESPONSE ACTIONS, TECHNOLOGIES, AND PROCESS OPTIONS

General Response Action	Technology	Process Option	Description	Relative Cost
Institutional Controls	• Monitoring	• Groundwater Monitoring	Perform routine sampling and analysis of upgradient and downgradient monitoring wells.	Low
		• Soil Sampling	Perform routine sampling and analysis of surface soils.	Low
		• Inspection	Perform routine inspections and observations of site conditions.	Low
	• Access Restrictions	• Deed Restrictions	Plat filed with county clerk describing location of wastes left in place.	Low
		• Site Security	Access restrictions maintained though fencing and patrolling.	Low
Containment	• Consolidation	• Onsite CAMU	Excavate and relocate contaminated soils into central location.	Low
	•	• Lined Buried Cell	Place contaminated soils in cell with underliner and multi-layer cap to provide total encapsulation.	High
	• Capping	• Soil Cover Cap	Cover contaminated soils with low-permeability soil cover to prevent human and ecological contact and reduce infiltration.	Moderate
		• Multi-Layer Cap	Cap contaminated soils with geosynthetic materials and low-permeability soil cover to further reduce infiltration and promote drainage of precipitation.	High
Physical Beneficiation	• Size Separation	• Screening	Use a screen or trommel to separate soils into component sizes. Often needed prior to other soil treatment processes to separate large particles over 1 to 6 inches in diameter.	Low
	• Gravity Separation	• Jig	Separate heavier lead concentrate from slurried soils using rhythmic pulsing of fluid in flow chamber.	Low
		• Hydrocyclone	Use cone-shaped static device to separate heavier lead concentrate from slurried soils through circular geometry of flow chamber.	Low

TABLE 6.1 (Continued)
SUMMARY OF GENERAL RESPONSE ACTIONS, TECHNOLOGIES, AND PROCESS OPTIONS

General Response Action	Technology	Process Option	Description	Relative Cost
		• Spiral	Use a trough wound around a central axis to separate heavier lead concentrate from slurried soils through circular flow around axis.	Low
		• Table	Use an oscillating rectangular tilted deck to separate heavier lead concentrate from slurried soils by passing slurry over riffles.	Low
		• Lead shot reclamation	Dry soil processing equipment for *in situ* removal of lead shot from surface soils	Low
Soil Treatment	• Acid Leaching	• Stirred or Vat Leaching	React slurried soil fractions and leach solution (such as hydrochloric acid) in a stirred tank reactor or leach tank.	High
	• Stabilization	• Portland Cement	Mix contaminated soils with Portland cement to reduce mobility of metals.	Low
		• Pozzolanic Materials	Mix contaminated soils with siliceous materials such as fly ash or lime kiln dust to reduce mobility of metals.	Low
		• Phosphorus-Based Chemical Fixation	Mix contaminated soils with phosphorus-based reagents to form insoluble apatite-like lead phosphate compounds (example: Maectite, Sevenson).	Moderate
		• Emulsion Fixation and Reuse	Mix contaminated soils with asphaltic cold-mix emulsion (or other proprietary emulsion), resulting in chemical fixation of lead in a recycled soil material product suitable for structural fill (Example: Encapco).	Moderate
Reclamation	• Smelting	• Secondary Lead Smelter	Excavate, transport, and dispose of off-site lead-contaminated soil by incorporation into an existing smelter stream; applicable to soils or concentrates with a minimum of 3 percent to 70 percent lead concentration.	Low
Phytoremediation	• Phytoextraction	• Ground Cover	Use metal-tolerant, hyperaccumulating vegetation to extract lead from soil.	Low
	• Phytostabilization	• Ground Cover	Use metal-tolerant vegetation to reduce erosion, leaching, and airborne dispersion.	Low
Disposal	• Offsite Disposal	• Nonhazardous Waste Landfill	Excavate, transport, and dispose of offsite contaminated soils at a permitted solid waste landfill; applicable to soils that pass the toxicity characteristic leaching procedure (TCLP).	Moderate
		• Hazardous Waste Landfill	Excavate, transport, and dispose of offsite contaminated soils at a permitted hazardous waste treatment, storage and disposal facility (TSDF).	High

Most of the technologies described in Table 6.1 are conventional remedial measures that apply to firing ranges as well as other contaminated sites (e.g., offsite disposal). Additional descriptions of technologies with unique applications to firing-range sites are provided in the following subsections.

6.2.1 Physical Beneficiation

Physical beneficiation includes conventional mineral extraction techniques that segregate soil particles according to size and differences in specific gravity to achieve separation of "light" materials from "heavy" materials. These techniques can be applied at some firing-range sites for separation of metallic lead particles from soil. Because both the sizing and the gravity separations are performed on slurried soils, physical beneficiation also can be described as soil washing.

Size Separation: While soil particles can range in size from large cobbles to microscopic particles, small-arms bullets and lead fragments from firing ranges fall into a narrower size range of about 0.5 inch to microscopic particles. Depending on the effects of munitions impacts and subsequent weathering, a portion of the bullet fragments may be near the original size of the bullet. In these cases, a screen can be used to separate larger lead particles from finer-grained materials. Thus, screening can potentially be a simple, low-cost way to remove a large portion of the lead in soils. Full-scale application of screening generally involves use of a trommel, which is a rotating cylindrical screen used industrially for ore processing and sand and gravel operations. The effectiveness of screening for lead removal needs to be assessed in a bench-scale treatability study.

Gravity Separation: Lead is a "heavy" material because it has a higher specific gravity than soil. The specific gravity of lead is 11.4 grams per cubic centimeter (cm^3), whereas the average for soil minerals is about 2.5 grams per cm^3. Gravity-separation devices such as jigs, hyrocyclones, spirals, or tables (operated separately or in combination) can be used to separate lead from soil by utilizing the differences in specific gravity. All of these gravity-separation devices treat a water/soil slurry. Gravity-separation techniques work very well on uniform particle size feed from which the very-fine-sized particles (i.e., silt and clay size particles less than 200 mesh or 75 μm) have been removed. If the very fine particles carry appreciable lead concentrations, this method is less effective.

Beneficiation has been successfully applied in pilot- and full-scale systems. For example, at the Naval Weapons Station Earle Sites 24 and 25, over 99 percent of the particulate lead was removed from berm material using size and gravity separation techniques, allowing for reuse of over 95 percent of the soil as fill. Approximately 5 percent of the soil from this site, consisting of clay fines that were separated during soil washing, could not be reused because the total lead concentrations exceeded the cleanup criterion of 400 ppm. A full-scale demonstration at Fort Polk also used beneficiation for bulk lead removal; additional treatment by acid leaching was required at this site to meet the cleanup criteria of 500 mg/kg total lead and less than 5 milligrams per liter (mg/L) for TCLP lead (Warminsky *et al.*, 1997).

6.2.2 Lead Shot Reclamation

Recovery of lead shot using conventional dry screening and gravity separation techniques has been performed at numerous skeet and trap ranges across the US. This type of equipment has been developed for mining and solids processing applications, and has been configured for removing lead shot from skeet ranges by at least one vendor: Gene Sears Supply Company of El Reno, Oklahoma. Although the configuration of equipment is unique to this vendor, the types of processing equipment are used for conventional metals recovery in mining operations, and therefore the process is not proprietary.

The lead shot reclaiming equipment is mounted on a semi-truck trailer, and has a hydraulically-operated ram that pushes a metal box with a cutting edge across the ground surface to cut a thin lift of soil in a 4-foot-wide swath. Typically, Sears has excavated the top 2 or 3 inches of soil at skeet ranges, and has found this to be adequate for removal of lead shot. As the trailer slowly traverses the site, soil is fed into the box and then into a conveyor with buckets to elevate the soil to the level of the trailer bed. From there it is fed into a dry shaker (conventionally used for gold mining), which is a combination of a screen with a tilted vibratory table (16 feet long by 4 feet wide). The soil must be dry for this process to be effective. As the lead shot and similar-sized soil material falls through the screen, it is further processed through a tumbler (to break up the clods and adhering dirt) and then run through a series of blowers to blow off the sand material from the shot. Soil and other excluded materials are then dropped back onto the ground surface behind the trailer as the equipment progresses. Because soil is removed, treated, and replaced in a continuous train, the process is considered to be an *in situ* treatment for lead shot removal.

6.2.3 Acid Leaching

Acid leaching can be used to remove lead from soils using chemical dissolution of lead in an acid, followed by recovery of the lead from solution. This is a highly refined practice in the mining and mineral extraction industries. Acid leaching is most applicable for dissolving fine lead particles; a screening or screening/physical beneficiation operation would be necessary to remove any large bullet fragments from the soil. Acid leaching may not be cost-effective if the soil contains much calcareous matter, because the basic nature of the soil would require a large amount of acid to acidify the solution. High acid consumption results in high reagent costs, and high solution disposal costs when the project is completed. A common leaching reagent used for lead removal is hydrochloric acid.

Large particles of lead cannot be leached in a reasonable (as defined by cost-effective throughput) length of time, so leaching is best applied to finer particle sizes as a supplement to physical beneficiation. Site-specific data are obtained by working with a representative sample that has been collected and processed by physical beneficiation. Acid leaching of fine-grained soils such as clays can be problematic due to final dewatering requirements as well as additional acid consumption due to buffering effects of the clay particles. An ideal soil type for acid leaching would consist of sands with little fines.

Leaching of firing-range soils was demonstrated at Fort Polk, Louisiana where both acetic acid and hydrochloric acid were evaluated. Results indicate that hydrochloric acid can be used to meet most leachable standards; however, the effectiveness of acetic acid is unproven (Batelle, 1997). Leaching costs are generally high compared to other treatment technologies such as stabilization because of the need to slurry the soil, the handling of low pH solutions, the consumption of acid reagents, and final neutralization and dewatering requirements of the treated soils.

6.2.4 Solidification/Stabilization

Solidification is the encapsulation or physical adhesion of waste on a micro or macro scale into a more solid material. Stabilization is the conversion of contaminants into a less soluble, less mobile, or less toxic form (USEPA, 1989c). Fixation is a term often used to refer to solidification or stabilization. Stabilization/solidification (S/S) is recognized by the USEPA as an effective remediation process for treatment of soils contaminated with lead and other metals (USEPA, 1997b). S/S technology is most promising where future access is relatively secure (such as continued use as a military base), because the lead will remain in the soil and may continue to pose a potential risk, long-term monitoring and record keeping are necessary to ensure that lead stabilization remains effective.

The primary goal for S/S at firing-range sites will typically be to reduce leachable lead levels below the TCLP hazardous waste criterion of 5 mg/L, or the universal treatment standard for soil of 7.5 mg/L. Several specific S/S technologies are potentially applicable to firing-range sites, as listed below:

- **Portland® Cement:** Conventional cement-based process in which waste materials are mixed with Type I Portland® cement.

- **Pozzolanic Materials:** Involves blending soils with siliceous and aluminosilicate materials. The primary containment mechanism is the physical entrapment of the contaminant in the pozzolans such as fly ash, pumice, lime kiln dusts, and blast furnace slag.

- **Phosphorus-Based Chemical Fixation:** Phosphorus-based stabilization involves the formation of relatively insoluble lead phosphates (e.g., pyromorphites) upon the application of sufficient quantities of apatite, calcium phosphate, phosphoric acid, or similar phosphorus-based material directly to the soil or soil slurry contaminated with lead.

- **Emulsion Fixation and Reuse:** Lead-contaminated soil can be blended with water-based asphalt emulsion (or other organic binder material) and varying amounts of aggregate to produce a range of cold-mix asphaltic products. These products can be used as structural backfill, parking lot pavement, and road construction material, as well as for chemical fixation (stabilization) of lead in soils. This method is most appropriate for sandy soils, not fine-grained soils.

6.2.5 Lead Reclamation

Lead present in firing-range soils can be reclaimed by processing through a secondary-lead smelter. Secondary-lead smelters routinely reclaim lead from spent lead-acid batteries. Waste material such as lead projectiles and concentrated lead-contaminated soil from firing ranges can be slowly fed into a smelter as an alternative to landfilling to reclaim the lead. The first step is to excavate, screen, and transport the bulk lead waste material to the secondary smelter. The smelter may be capable of pre-processing the soils prior to introduction into the smelter waste stream at a rate dependent on lead content, size of material, and fuel values.

Recent work by Paff and Bosilovich (1995) indicates that secondary-lead smelters may be able to reclaim contaminated material containing 3 to 70 percent lead. Factors to be evaluated when assessing this alternative are availability of a secondary smelter willing to process the waste, excavation and transportation costs, and costs for pre-processing. Lead reclamation has been used at firing-range sites for partial recovery of high-grade lead concentrates removed from site soils using physical beneficiation techniques.

6.3 TREATABILITY STUDY RESULTS

Treatability testing will generally be required to assess treatment options for lead in firing-range soils. For example, bench-scale testing is recommended to provide preliminary data on the effectiveness and approximate costs associated with lead removal from soils using physical beneficiation techniques.

Based on the results of this and other firing-range studies, the particle-size distribution of lead in firing-range soils varies widely from site to site. Figure 6.1 shows the particle-size distribution of lead in firing-range and skeet-range soils investigated under this initiative. The relative proportions of lead in specific size ranges can greatly impact the ability to cost-effectively remove the lead to below action levels. For example, at the skeet-range site in Texas, the removal of residual shot could easily be performed using physical beneficiation techniques. However, removal of significant lead in particle sizes less than 200 mesh can be problematic, as shown for the small-arms range sites in California and Texas (Figure 6.1).

The objective of treatability testing is to identify the most cost-effective treatment(s) that can effectively reduce the potential risk to human health and the environment posed by exposure to lead. While other metal COCs may also pose a risk, it is possible that the removal of lead from soil will result in effective removal of other metals as well. Specific objectives of treatability testing can include:

- Determining the distribution of lead particle sizes in site soils to support the FFS evaluation.

- Determining the quantity of lead that can be removed from site soils using physical beneficiation. This will include assessing the effectiveness of physical and gravity separation to reduce lead in soil to the risk-based cleanup goals.

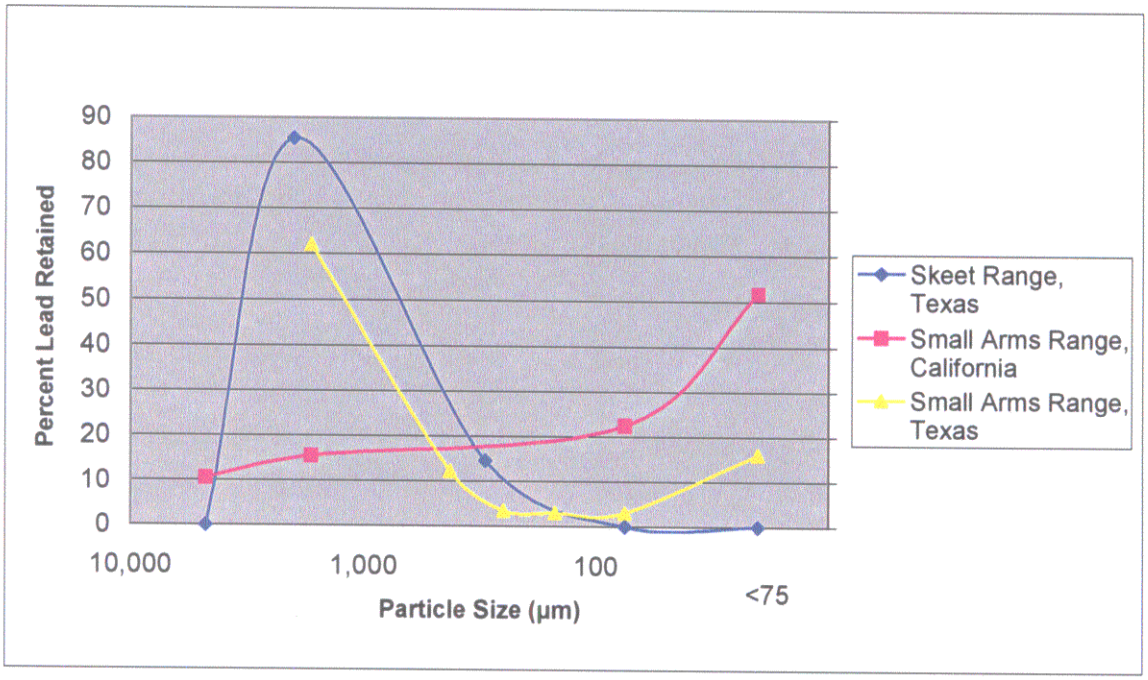

Figure 6.1 Lead Concentrations in Soil Size Fractions

- Assessing the effectiveness of stabilization of soil that has undergone physical/gravity separation pretreatment for lead removal, and that does not meet the risk-based action levels or leachability standards (i.e., TCLP).

An example bench-scale treatability test plan for firing-range soils is provided in Appendix F. Care should be taken in the field to ensure that bulk samples sent to the treatability study laboratory are representative of the soils that require remediation at the site.

6.4 REMEDIAL ALTERNATIVES AND CRITERIA FOR EVALUATION

The remedial technologies and process options retained after site-specific screening (Table 6.1) should be assembled into remedial alternatives for further detailed evaluation. The alternatives should represent a broad spectrum of remedial approaches to address contaminated soils.

Typical Remediation Alternatives for Small-Arms Ranges
• Alternative 1 – Limited action (e.g., institutional controls with monitoring) • Alternative 2 - Soil cover or on-Base consolidation (may include stabilization) • Alternative 3 – Excavation of soils and onsite treatment • Alternative 4 – Excavation of soils and offsite treatment and disposal

The limited action alternative is suggested, rather than a No Action alternative, to accommodate the reasonable probability that some form of control will be required for a

firing-range site that poses a potential risk. Limited action will generally provide the least costly remedial option but may not be sufficiently protective, especially for ecological receptors. However, institutional controls such as fencing as well as signage and site security may provide sufficient protection of potential human receptors, in some cases.

The detailed analysis of each alternative is based on nine evaluation criteria outlined in the NCP (40 CFR 300.430) and USEPA (1988) guidance for Superfund sites. Each alternative should be assessed to determine how well it meets the following criteria:

- Overall protection of human health and the environment,
- Compliance with ARARs,
- Long-term effectiveness and permanence,
- Reduction of toxicity, mobility, or volume of COCs,
- Short-term effectiveness,
- Implementability,
- Cost,
- Regulatory acceptance, and
- Community acceptance.

A summary of the alternatives evaluated and the preferred remedy selected for each of the sites evaluated under this initiative is presented in Table 6.2. Typically consolidation into an onsite disposal area was determined to be a preferred remedial option for these sites. One base in California already had plans for an on-base CAMU for consolidation of contaminated soils from several restoration sites. The CAMU was selected as the preferred remedy for the firing-range site. For the small-arms range in Texas, the base was able to obtain regulatory approval for disposal of stabilized firing-range soils in an on-base landfill, which was the most cost-effective option. For the skeet range in Texas, lead shot reclamation was determined to be the preferred alternative that met RAOs based on cost effectiveness.

Following selection of a preferred alternative for a site, ***a SMDP is recommended to gain regulatory concurrence on the proposed remedial approach.***

TABLE 6.2
SUMMARY OF ALTERNATIVES FOR REMEDIATION OF RISK-BASED FIRING-RANGE SITES

	Volume Requiring Remediation	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Small-Arms Range, California	1,460 bcy[a/] (2,400 tons)	Limited Action	Consolidation and Capping	Excavation and Onsite Treatment	**Excavation and On-Base Disposal at CAMU**[b/]	Excavation and Offsite Disposal
		$114,600	$330,700	$1,571,800	$350,000/$481,400 (if treatment required)	$675,500
Small-Arms Range, Texas	8,700 bcy (14,500 tons)	Limited Action	**Consolidation and Capping**	Excavation and Onsite Treatment	Excavation and Offsite Disposal	--
		$101,000	$502,000	$1,850,000	$3,000,000	--
Small-Arms Range, Alaska	None	No alternatives evaluated, **No Further Action** recommended				
Skeet Range, Texas	4,600 bcy (7,500 tons)	Limited Action	Consolidation and Capping	Excavation and Onsite Treatment	**Lead Shot Reclamation**	Excavation and Offsite Disposal
		$86,000	$276,000	$666,000	$173,000	$473,000

[a/] bcy = Bank (in-place) cubic yards.

[b/] Recommended alternative is in bold.

SECTION 7

DELIVERABLES

The purpose of this section is to provide RPMs with practical guidance on completing the documentation that will be required to present a risk-based approach to small-arms range remediation to regulators and the public. Suggestions for how to improve the quality of regulatory interactions are provided in this section, along with methods for educating the public on the subject of risk and risk-based remediation.

A successful project begins with a well-developed work plan that outlines the entire remedial approach and sets forth the objectives of a risk-based closure. Once site data are collected and analyzed, and a risk-based remediation approach is formulated for a site, the findings must be organized and presented in a format that is acceptable to the regulators and that clearly communicates the risk evaluation process and recommended remedial approach. Outlines for work plans and remedial action plans are provided in this section. Suggestions for developing and presenting an effective briefing to summarize a risk-based remedial decision also are provided.

7.1 GAINING REGULATORY ACCEPTANCE

Before a risk-based remediation project is initiated, it is essential that the proper regulatory framework be established and the responsible regulatory officials be informed of planned characterization, risk assessment, and FFS efforts. Regulatory acceptance will always depend in part upon the existing level of trust and respect that exists between the base and the agency. In addition, the following actions are helpful in building regulatory acceptance:

- Base environmental managers and contractors who are well-versed in local risk-based regulations/guidance as well as the approach provided in this protocol.
- Informal discussions with the regulators about the site and a potential risk-based closure.
- Informal regulatory input should be sought to help focus the work plan on issues of interest to the state or USEPA. A key issue is the regulatory agencies' position on the current and future land use designations (industrial vs. a potential residential scenario). Agreeing that the site is and will remain an industrial or recreational/open space area can streamline the risk evaluation process.
- Regular communication throughout the duration of the project (i.e., using SMDPs).

7.2 PREPARING A WORK PLAN

The purpose of this subsection is to provide an outline of an example risk-based corrective action work plan. This is a comprehensive outline that can be abbreviated if significant site information already exists or modified to meet specific regulatory requirements. At large or complex/controversial sites, the work plan may receive a complete regulatory review. At smaller (low-risk) sites, regulatory review of the work plan may not be necessary. However, regulatory review of the work plan can serve as the primary SDMP and will minimize the potential for supplemental work as the project moves forward. Regardless of the level of regulatory interest, the work plan must clearly communicate the intentions of the Air Force to collect additional data and the intended use of the data in the risk-based process.

Example Work Plan Outline For Risk-Based Remediation

SECTION 1 - INTRODUCTION
SECTION 2 - SITE DESCRIPTION AND PREVIOUS INVESTIGATIONS
2.1 Site Location and Background
2.2 Land Use
2.3 Physical Setting
- 2.3.1 Climate
- 2.3.2 Topography
- 2.3.3 Surface Water
- 2.3.4 Geology/Stratigraphy
- 2.3.5 Hydrogeology/Groundwater
- 2.3.6 Ecological Setting

2.4 Review of Available Site Data
SECTION 3 - RISK-BASED APPROACH TO REMEDIATION
3.1 Description of Risk-Based Approach
3.2 Bioavailability of Lead
- 3.2.1 Particle Size
- 3.2.2 Lead Speciation
- 3.2.3 Bioavailability Analysis

3.3 Conceptual Site Model
3.4 Data Needs
SECTION 4 - DATA COLLECTION ACTIVITIES
4.1 Ecological Characterization
4.2 Soil Sampling
- 4.2.1 Surface Soil Sampling
- 4.2.2 Subsurface Soil Sampling
- 4.2.3 Trench Soil Sampling
- 4.2.4 Establishing Sampling Locations

4.3 Metals Analysis
- 4.3.1 Field Tests
- 4.3.2 Laboratory Tests

4.3.2.1 Total Lead
4.3.2.2 Total Metals Analysis
4.3.2.3 TCLP Analyses
4.3.2.4 Parameters for Physical Characterization and Threat to Groundwater Analysis
4.3.2.5 Lead Speciation Analyses
4.3.2.6 Lead Bioavailability Analyses
4.4 Treatability Testing
4.5 Management of Investigation-Derived Waste
SECTION 5 - PREPARATION OF THE REMEDIAL ACTION PLAN
5.1 Site Characterization
5.2 Risk Evaluation
5.2.1 Ecological Risk Analysis
5.2.2 Human Health Risk Analysis
5.3 Evaluation of Remedial Alternatives
SECTION 6 - PROJECT MANAGEMENT PLAN
6.1 Base Support Requirements
6.2 Project Schedule
6.3 Points of Contact
SECTION 7 - REFERENCES CITED
APPENDICES
A - Proposed Treatability Study
B - Proposed Human Health Exposure Parameters

7.3 PREPARING THE REMEDIAL ACTION PLAN

For sites that do not qualify for immediate closure, some form of remedial action plan (RAP) will be required to describe the actions that will be taken to achieve site closure. This subsection provides a document outline that has been used to gain regulatory approval of risk-based site closure agreements at several AFCEE demonstration sites. The same general outline can be used to satisfy the requirements for RAPs, corrective action plans (CAPs) and engineering evaluation/cost analysis (EE/CA) reports. Minor modifications will be required to satisfy USEPA or state-specific requirements, but the essential elements of most reports will be satisfied by this outline.

Example Remedial Action Plan Outline

1.0 INTRODUCTION
1.1 Purpose and Scope
1.2 Overview of Firing Range Characteristics
1.3 Report Organization
2.0 SUMMARY OF SITE CHARACTERIZATION ACTIVITIES
3.0 PHYSICAL CHARACTERISTICS OF THE SITE
3.1 Site Background
3.2 Regional Topography and Surface Water Hydrology
3.3 Regional Geology and Hydrogeology
3.4 Site Topography and Surface Water Hydrology

7.4 PREPARING A NO-FURTHER-ACTION CLOSURE DOCUMENT

An NFA (no-further-action) closure document can be prepared for sites where contaminant levels are already below risk-based cleanup criteria, or for sites where there are no completed exposure pathways to potential receptors, and the state is willing to grant closure based on risk-based evidence and adequate institutional controls. Many states require a brief report on site conditions and characterization data that indicates compliance with risk-based cleanup goals. The content of these documents is generally spelled out in regulatory guidance. Key components of most no-further-action documents include:

- A brief site description;
- A site map which clearly describes existing land use and surface features;
- A map showing the location of soil and (if applicable) groundwater samples;
- A table or graph comparing maximum or average contaminant values to risk-based cleanup criteria; and
- A discussion of institutional controls and how they will be maintained if contaminants exceed risk-based cleanup goals.

7.5 EFFECTIVE PRESENTATIONS

There is no substitute for good communications, including face-to-face meetings with regulators, at key decision points in the risk-based corrective action process. Several suggestions are offered to help improve the general effectiveness of presentations to the regulatory community and general public:

- Plan for a minimum of two face-to-face meetings, one to describe the risk-based approach for the site (a review of the work plan), and a second to describe the recommended remedial approach based on the risk evaluation.

- Know your audience, their technical strengths and weaknesses, and their sensitivities and priorities. If your regulatory contact lacks experience, a major portion of the presentation should focus on reviewing the Air Force remediation strategy. Presenting a simple case study of a completed risk-based closure can facilitate this process.
- Use simple and professionally prepared graphics. There is no substitute for a good picture to illustrate a conceptual site model or to display lead concentrations on a site map. For most audiences, a "picture is worth a 1,000 words".
- Minimize the use of jargon (e.g., unfamiliar acronyms and terminology). This requires a concerted effort because the risk evaluation process is noted for having its own language and code words.
- Make sure that your presentation stresses that these are Air Force "recommendations" and that your actions are "proposed". Regulators need to get a clear message that the Air Force recognizes the regulatory role in the decision-making process.
- Leave time at the end of the meeting for questions. Encourage the audience to write down their questions, and try to resolve as many questions as possible at the meeting. Make sure you have someone in the room who was involved in the field work and risk evaluation, as most questions seem to fall into these two categories.
- Always provide a set of meeting minutes to the participants within a week of the meeting, including a list of action items and who is responsible for resolution.

Finally, there is no substitute for preparation and practice. If a consultant will be making the presentation for the Air Force, it is important to arrange a pre-brief so the Air Force "team" understands the major conclusions and recommendations and is prepared to answer predictable questions.

SECTION 8

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APPENDIX A

CONCEPTUAL SITE MODELS, DATA USABILITY, AND EXPOSURE-POINT CONCENTRATIONS

The purpose of this appendix is to discuss the steps involved in 1) developing a conceptual site model (CSM); 2) determining data usability for risk assessment purposes; and 3) calculating exposure-point concentrations (EPCs). The CSM is used to summarize availaible site information, identify data gaps, and present receptor exposure hypotheses. Data usability should be evaluated following the guidelines described in *Guidance for Data Usability in Risk Assessment (Part A)* (USEPA, 1992c) and *Risk Assessment Guidance for Superfund (RAGS)* (USEPA, 1989a). EPCs are intended to be representative of the concentrations of chemicals in a given medium to which a receptor may be exposed (i.e., the exposure point). These topics are reviewed in this appendix.

A.1 DEVELOPING A CONCEPTUAL SITE MODEL

A preliminary CSM should be developed for inclusion in the work plan for a risk-based approach to remediation at a firing-range site. The CSM is used to identify data gaps that can be addressed during the field effort. The contaminant sources, affected media, land use, exposure assumptions, receptors, and exposure routes are summarized in the CSM. Once field data are collected and analyzed, the preliminary CSM is revised in light of new information, and pathways for receptors potentially exposed to contaminants in soils are clarified (Step 1 in Figure 4.1). CSMs can be constructed in several forms, including schematics, flow diagrams, and tables. An example of a flow-diagram CSM is provided as Figure 3.1.

Only completed exposure pathways between site contaminants and receptors are evaluated in the risk assessment. For a current or future exposure pathway to be completed, each of the following four elements must be present:

- A source of contamination,
- A mechanism for contaminant transport,
- A receptor exposure point, and
- A receptor and a route of exposure.

If any of these elements is lacking, the pathway is incomplete, and the contaminant poses no risk to the receptor. An exposure pathways analysis is conducted based on current site

information and planned future land uses to determine which pathways are or may be completed for receptors exposed to affected site media. Exposure routes at a terrestrial firing-range site may include ingestion, inhalation of particulates, and/or dermal absorption for humans and terrestrial or avian wildlife, and assimilation through uptake for soil invertebrates and plants. Site conditions and the current and future expected land uses of the firing-range site and vicinity are the basis for identifying the receptors potentially at risk from site-related contaminants.

A.1.1 Information Needed to Develop the CSM

The CSM is constructed based on the answers to a series of questions about site history, environmental characteristics, land use, and the nature and extent of firing-range contamination. In answering the questions that will shape the risk evaluation, it is important to remember that the risks/hazards to be evaluated typically are those that may occur under chronic (long-term) rather than acute (short-term or one-time) exposure scenarios. Some of the questions that should be answered to construct a CSM that accurately represents potential links between site contamination and receptors (i.e., exposure pathways), and that can be used to identify and fill data gaps during a risk-based approach to remediation, are discussed in the following subsections.

A.1.1 Contaminant Sources, Affected Media, and Release Mechanisms

- The nature, magnitude, and extent (i.e., vertical and lateral distribution) of firing-range contaminants in site soils:
  - Based on all available site data, what types of small arms were discharged at the site (e.g., rifles, pistols, shotguns)? Are target structures or debris present (e.g., impact berms, fragments of trap or skeet targets)?
  - Have the lateral and vertical extents of soil contaminants, including areas of higher concentration (e.g., firing lines, impact berms, shot/target fallout patterns), been fully delineated?
- Contaminant fate and transport processes that may alter the nature and/or extent of soil contamination at the site, thereby affecting completed exposure pathways:
  - Is there evidence that media other than site soils have been impacted (e.g., surface water, groundwater, vegetation)?
  - Do local climatic, topographic, ecological, or cultural conditions (e.g., significant annual precipitation, floodplain location, plant cover, or irrigation) indicate a strong potential for aerial dispersion of particulates, leaching, erosion, periodic flooding, permafrost, or frost heave?
  - Have natural or artificial ground-disturbing activities (e.g., animal burrowing, frost heave, grading) resulted in mixing of contaminated soils or concentrations of contaminants?

A.1.2 Environmental Conditions and Land Use

- Current and expected future environmental conditions and land uses at and near the site:

  - What percentages of the site area are vegetated, developed (e.g., with structures, pavement, or recreational facilities), or bare ground (e.g., due to stressed vegetation, grading, or parking areas)?

  - Is the vegetated portion of the site maintained (e.g., irrigated, mowed, tilled, subject to weed or pest control practices)?

  - Do vegetated areas provide suitable habitat for wildlife, and if so, which species may be present?

  - Does site topography and/or development promote precipitation infiltration into site soils, runoff to a stormwater management system, or runoff into surface water drainages/bodies?

  - Is site access restricted, and if so, by what means (e.g., remote location, security fencing, patrols)?

  - Have any site remediation or redevelopment activities been undertaken at the site since firing-range operations ceased? Has the site been used for other purposes since range activities ceased?

  - Does the Base have a land use plan? If so, does the land use plan call for redevelopment or other changes in current uses of the site and/or its immediate surroundings? What are the planned land uses, if any?

A.1.3 Receptors and Exposure Routes

- The types of human and ecological receptors that might be expected to visit or reside at the site under these land use scenarios, and how they might be exposed to site contaminants (i.e., ingestion, dermal contact, uptake [for plants], and/or inhalation):

  - Based on current and future land use information, what human receptors may frequent the site (e.g., groundskeepers, construction workers, hunters, recreators, residents)?

  - To which affected media (e.g., surface soils, subsurface soils, air) and via which exposure routes (e.g., incidental soil ingestion or inhalation of particulates in fugitive dust) might these human receptors be exposed?

  - Based on current and expected site ecology, access, and land use, what types of ecological receptors may be present at the site (e.g., non-domesticated plants,

soil invertebrates, mammals, birds, reptiles), and what in sorts of activities might they engage (e.g., nesting, burrowing, foraging, hunting, breeding)?

- What trophic levels predominate at the site?

- Does the site provide suitable habitat for any protected or other special-concern species (e.g., federally or state-listed threatened or endangered species, migratory birds, game animals)?

- To which affected media (e.g., surface soils, subsurface soils in the rhizosphere, biota that have accumulated contaminants in tissues) and via which exposure routes (e.g., incidental soil ingestion, consumption of contaminated plants or prey animals) might ecological receptors be exposed?

Once the questions listed above have been answered, the CSM can be refined, and appropriate receptors can be selected for evaluation, as described in Sections 4.2 and 4.3. For human health risk assessments, constructing an exposure pathway selection table that lists the exposure pathways considered and the rationale for including/excluding exposure pathways can facilitate review. This table is recommended by USEPA (1998b) RAGS Part D. For ecological risk assessments, constructing a simple food web diagram for the site can help reviewers determine that ecological receptors selected for evaluation are appropriate for the site. A food web diagram is provided in Appendix D.

A.2 EVALUATION OF ANALYTICAL DATA FOR USABILITY IN RISK ASSESSMENTS

Depending on the affected media and potentially exposed receptors at a given site, the usability of analytical data (current and historic) in the human and ecological risk assessments needs to be addressed. After combining analytical data that meet project data quality objectives and eliminating those analytes not detected in any samples in a particular medium, the data should be evaluated further on the basis of quality, with respect to method detection limits (MDLs) and sample quantitation limits (SQLs), laboratory qualifiers, blanks, duplicates and replicates, and compounds analyzed using multiple analytical methods. All data used in the site characterization and risk assessments should be validated in accordance with the project Quality Assurance Program Plan (QAPP). The QAPP typically is reviewed and approved by the regulatory agency during the work plan phase of the project. The site characterization/investigation activities should not commence without an approved work plan (including a QAPP). ***A scientific/management decision point (SMDP) should be used to ensure concurrence with the QAPP.*** Based on *Guidance for Data Useability in Risk Assessment (Part A)* (USEPA, 1992c) and *RAGS* (USEPA, 1989b), validated analytical data should be used in the risk assessments, as described in the following paragraphs. Data that are to be included in the risk assessments should correspond to the appropriate human and ecological receptor exposure intervals (Section 4.1). In addition, the effect of soil particle size on detected lead concentrations should be evaluated as described in Appendix C.

Unqualified (i.e., detected and valid) analyte values should be included in the risk assessment data sets, and rejected ("R"-qualified) data should be excluded from the risk

assessment data sets. Per USEPA (1992c), "Data qualified with an R are rejected because performance requirements in the sample or in associated quality control (QC) analyses were not met." An example might be a mass spectrometer that is "out-of-tune," which results in unacceptable confidence in the identification and quantitation of a chemical. Analytes not detected ("U"-qualified) in any sample of a given matrix at a site should be excluded from the quantitative risk assessment data set for that matrix. A comparison of the detection limits with risk-based screening levels (i.e., levels protective of human health and the environment) should be performed during the development of the work plan. The results of this comparison should be discussed in the uncertainty sections of the risk assessments.

Values reported as estimated ("J" qualified) should be included in the risk assessment data sets and used the same way as positive data that do not have this qualifier (USEPA, 1989a and 1992c). Data qualified as "J" indicate uncertainty in the reported concentrations, but not in the assigned identities and are "estimated" because quantitation in the samples or in the associated quality control samples do not meet validation criteria. Potential uncertainties associated with the use of J-qualified data should be discussed in the risk assessments.

If a chemical is detected at least once in a specific medium, surrogate values for any nondetects ("U" qualified results) for that analyte generally should be included in the risk assessment data sets at one-half the associated SQL. In other words, "U" qualified data generally will be useable in assessing potential exposure (USEPA, 1989b). Per USEPA (1992c), "The SQL is the MDL adjusted to reflect sample-specific action such as dilution or use of a smaller aliquot for analysis due to matrix effects or the high concentration of some analytes." SQLs are used in the data evaluation step because they take into account sample characteristics, sample preparation, and analytical adjustments, and are considered to be the most relevant quantitation limits for evaluating nondetected chemicals (USEPA, 1989b). However, if the SQL for a given nondetect sample is significantly greater than the maximum detected concentration for the given analyte in a specific matrix within an exposure area (e.g., a SWMU boundary), the datum may be considered anomalous and potentially may be excluded from the risk assessment data sets. USEPA (1989b) recommends excluding nondetected results from the risk assessment data set if the SQL is "unusually high" or if they cause the estimated exposure concentration to exceed the maximum detected concentration for a particular data set. ***Use a SMDP to ensure regulatory concurrence with the proposed approach.***

When two or more values are available for a given sample/location/date (e.g., duplicates or replicates), the average or maximum of the values may be used. If all values for a given sampling location are nondetects, and a value is required for the risk assessment data set (i.e., other sampling locations at the site have unqualified or "J"-flagged values), the value with the lowest SQL should be selected. If at least one value is unqualified or "J"-flagged and the other value(s) is a nondetect, the maximum detected value may be used or an average can be calculated assuming one-half the SQL for the nondetect(s). Again, if the SQL for a given nondetect sample is significantly greater than the maximum detected concentration for the given analyte in a specific matrix within the exposure area (e.g., site boundary), the datum should be considered anomalous and

should be excluded from the risk assessment data set. ***Use a SMDP to ensure regulatory concurrence with the proposed approach.***

A.3 EXPOSURE-POINT CONCENTRATIONS

EPCs should be estimated using analytical data obtained from onsite sampling, either directly or as modeling parameters. The EPCs for ingestion and dermal contact (for human receptors) should equal the representative site concentrations for the affected soil exposure intervals. EPCs for human exposures to metals (i.e., particulates) or organic chemicals of potential concern (COPCs) (e.g., polycyclic aromatic hydrocarbons [PAHs]) in air should be estimated as described in *Soil Screening Guidance: Technical Background Document* (USEPA, 1996b). EPCs for ecological receptor exposures via ingestion of biota should be modeled using USEPA-approved methods (e.g., USEPA, 1993b). Steady-state soil concentrations are assumed for the COPCs (i.e., current concentrations in soil are assumed to be representative of future soil concentrations). The determination of soil and air EPCs are discussed in the following subsections.

A.3.1 Soil EPCs

COPC EPCs can be calculated for each soil exposure interval (e.g., 0-0.5 foot [ft] below ground surface [bgs] and 0-10 ft bgs). USEPA (1992a) recommends use of the arithmetic mean as the preferred parameter of a data distribution to represent the EPC (e.g., 95-percent upper confidence limit [UCL] on the mean), regardless of the distribution that best describes the sample data. However, calculating a 95-percent UCL on the arithmetic mean for environmental data sets can be problematic. In fact, one of the more difficult problems in the analysis of environmental data involves estimating population statistics, such as the arithmetic mean, and their associated uncertainty (i.e., confidence limits) in the presence of nondetects (i.e., censored data). Different methods can be used to estimate UCLs, depending on the percentage of nondetects, the locations of the nondetect values in the statistical distribution, and the number of samples in the data set. Examples of statistical approaches that can be used to estimate UCLs are described in the following paragraphs. However, an environmental statistician should be consulted prior to performing any statistical analysis. ***In addtion, use a SMDP to ensure regulatory concurrence with the proposed approach.***

If the sample size and the percentage of nondetect values permit the calculation of statistically appropriate UCLs, then the lesser of the maximum detected value and the 95-percent UCL should be used as the EPC for COPCs in soils. Steady-state conditions typically are assumed for soil concentrations of COPCs, and therefore, estimated soil EPCs will represent current and future concentrations. The standard UCL formula (Rice, 1995) is applied when the data adequately fit a normal distribution. For data that do not fit a normal distribution, USEPA (1997c) recommends applying a nonparametric method to estimate the 95-percent UCL. USEPA (1997c) no longer recommends the use of the H-statistic when calculating UCLs for data that are log-normally distributed.

USEPA (1992d) recommends several statistical procedures for determining whether the distribution of site data is normal. One such recommended procedure is the Shapiro-Wilk test. Site COPC data are tested for normality by applying the Shapiro-Wilk test to

the untransformed data. The Shapiro-Wilk test returns a "p-level" value between 0 and 1, indicating the goodness of fit. A p-level of 0.05 or greater indicates an acceptable fit to a normal model at the 95th-percentile confidence level. If the Shapiro-Wilk test indicates that a data set is normal at this confidence level, the data are considered to have a parametric distribution. Per USEPA (1989d) guidance, data sets with greater than 15-percent nondetects are automatically treated as nonparametric distributions. Graphical plots of the data (e.g., probability and/or box-and-whisker plots) should be reviewed as a quality control check on the results of the Shapiro-Wilk test (particularly for data sets where sample sizes are less-than 15-20).

Examples of statistical approaches that can be used to calculate soil EPCs are discussed in the following subsections.

A.3.1.1 UCLs for Normally Distributed Data

To calculate the 95-percent UCL for normally distributed data, the arithmetic mean and standard deviation of the untransformed data are calculated, and the one-tailed t-statistics are determined from Gilbert (1987). Nondetected values are assumed to equal one-half the SQL for the 95-percent UCL calculations. The 95-percent UCL is calculated for each COPC (within the approprieate exposure interval) using untransformed data as described by Gilbert (1987).

$$95\text{-Percent UCL} = \bar{x} + t(s/(\sqrt{n}))$$

where:

$\bar{x}$ = arithmetic mean of the untransformed data;

s = standard deviation of the untransformed data;

t = one-tailed Student's-t statistic (Gilbert, 1987); and

n = number of samples.

A.3.1.2 UCLs for Other Data Distributions

Nonparametric 95-percent UCLs should be used when the distribution of the data is not normal (USEPA, 1997c). In particular, the "percentile" bootstrap method recommended by USEPA (1997c) for censored data (Efron, 1981) can be used to calculate the 95-percent UCL on the median of analyte-specific data sets. This method estimates the UCL by simulation and has been shown to have good theoretical coverage properties and reasonable stability in practice (Efron and Tibshirani, 1993). The percentile method is applied by randomly sampling the given data set with replacement and calculating the median.

The bootstrap method also can be used when the proportion of nondetects in a data set is equal to or greater than 15-percent. The bootstrap method, described above, is

considered a robust method for these data conditions, and is conservative for handling nondetects when the proportion is greater than 15-percent and one-half the SQL is substituted for the nondetects. Robust methods are a family of statistical procedures specifically designed for censored data. Gibbons (1994) notes that this simple substitution creates a positive (i.e., conservative) bias when the percentage of nondetects is high.

A.3.2 AIR EPCS

The inhalation route is not quantitatively evaluated for ecological receptors due to a lack of toxicity information, but is evaluated in the human risk assessment. Because air monitoring data typically are not available, the inhalation exposure route can be evaluated using appropriate soil-to-air models. For example, USEPA (1996b) provides detailed algorithms for estimating particulate emissions from surface soils.

APPENDIX B

HUMAN HEALTH RISK ASSESSMENT METHODOLOGY

The results of a site-specific human health risk assessment (HRA) provide estimates of potential risks and/or hazards to human health associated with exposure to site-related chemicals. As shown in Figure B.1, HRA is a four-step evaluation process that includes (USEPA, 1989a):

- Data collection/evaluation and identification of chemicals of potential concern (COPCs) (i.e., hazard identification);
- Exposure evaluation;
- Toxicity evaluation; and
- Risk characterization.

The HRA needs to be performed using applicable state and/or USEPA (e.g., 1989a, 1992e, 1993c, 1994c, 1996b, 1996c, and 1997d) guidance. Development of human health risk-based remediation goals for soil COPCs also must follow applicable state and federal guidance. HRA and risk-based remediation goal derivation-methods are discussed in this appendix. Given the different approaches used to assess risks/hazards associated with potential exposure to lead and non-lead COPCs, the following subsections include separate discussions for lead and non-lead COPCs when necessary. An outline of the following subsections is provided in Figure B.1.

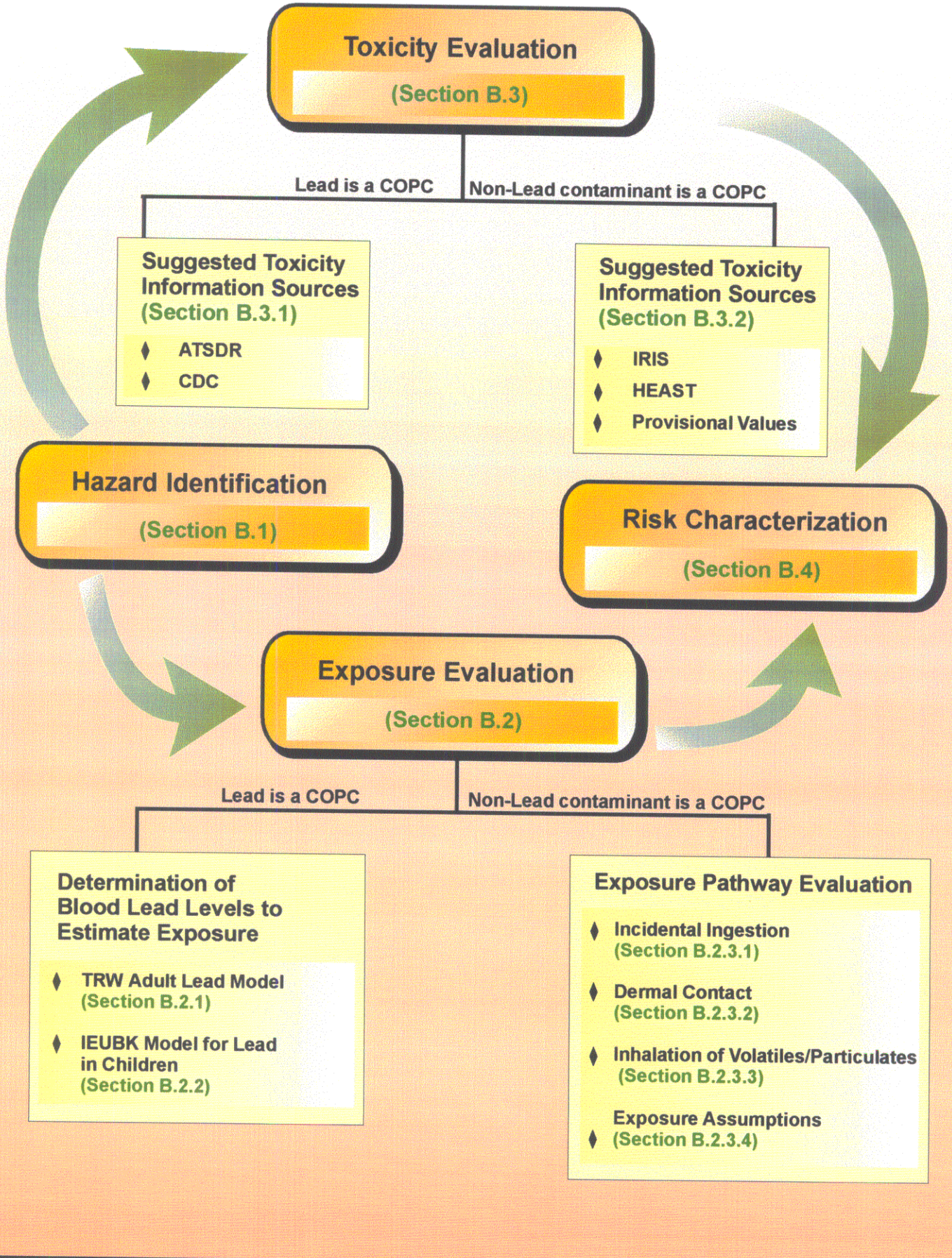
B.1 HAZARD IDENTIFICATION

Per USEPA (1989a), the hazard identification step involves collecting and reviewing all relevant site data and identifying COPCs (i.e., chemicals with a potential to pose unacceptable risks/hazards to the identified receptors). Methods for the collection and review of all site data, including a review of the physical characteristics of the site and the nature and extent of contamination, have been discussed in Section 3. Excluding chemicals attributed to field or laboratory contamination, COPCs are identified using one or more of the following steps:

- Elimination of essential nutrients;
- Analysis of the frequency-of-detection;
- Comparison of site concentrations to background concentrations for metals in like media (i.e., site-attribution analysis); and/or
- Risk-based toxicity screening.

FIGURE B.1

HUMAN HEALTH RISK ASSESSMENT METHODOLOGY



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Each of these steps have been discussed in Section 4 and/or Appendix A.

B.2 EXPOSURE EVALUATION

The objective of the exposure evaluation is to estimate the type and magnitude of potential exposures to site COPCs. The results of the exposure evaluation are combined with results from the toxicity evaluation to characterize potential risks. Per USEPA (1989a), exposure evaluation is a three-step process involving characterization of the exposure setting, identification of exposure pathways, and quantification of exposure. Characterization of the exposure setting and the identification of potentially exposed receptors and exposure pathways have been discussed in Section 4 and Appendix A. Examples of commonly identified potential receptors include adult nonintrusive and/or intrusive industrial workers and future residents. Methods to quantify potential exposure of adult and child receptors to lead and non-lead COPCs, including parameter selection/justification, are discussed in the following subsections.

B.2.1 Adult Blood Lead Levels

Methods to quantify potential exposure of adult receptors to lead in site soils, including algorithms and parameter selection/justification are described in the following subsections.

B.2.1.1 Algorithms for Estimating Adult Blood Lead Levels

Per USEPA (1996c), fetuses and neonates are a highly sensitive subpopulation of potential concern due to the adverse effects of lead exposure on development. Fetal blood lead concentrations can be estimated using the approach described in *Recommendations of the Technical Review Workgroup (TRW) for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil* (hereafter referred to as the TRW Adult Lead Model) (USEPA, 1996c). The TRW model is based on a simplified representation of lead biokinetics to predict quasi-steady-state blood lead concentrations among adults with relatively steady patterns of site exposures. The TRW's approach is consistent with that used for estimating risks to children (USEPA, 1994c). Given the assumption that fetuses and neonates comprise a highly sensitive subpopulation, reducing/preventing risk from the exposure to lead for these receptors also will be protective of adult receptors. TRW believes this approach is useful for assessing potential risks associated with lead exposures at most sites where places of employment are (or will be) located on lead-contaminated soils.

Equation 1 describes the estimated relationship between the blood lead concentration in adult women and the corresponding 95th percentile fetal blood lead concentration ($PbB_{fetal,\ 0.95}$), assuming that $PbB_{adult,\ central}$ reflects the geometric mean of a lognormal distribution of blood lead concentrations in women of child-bearing age (USEPA, 1996c).

$$PbB_{fetal,0.95} = (PbB_{adult,central})(GSD_{i,adult}^{1.645})(R_{fetal/maternal}) \quad \text{(Eq. 1)}$$

Where:

$PbB_{fetal,\ 0.95}$ = Estimated 95th percentile blood lead concentration (µg/dL) among

fetuses born to women having exposures to lead in soils.

$PbB_{adult, central}$ = Central estimate of blood lead concentrations (µg/dL) in women of child-bearing age that have site exposures to lead in soil.

$GSD_{i, adult}$ = Estimated value of the individual geometric standard deviation (dimensionless); the GSD among women of child-bearing age that have exposures to similar onsite lead concentrations, but that have nonuniform response (intake, biokinetics) to site lead and nonuniform offsite lead exposures. The exponent, 1.645, is the value of the standard normal deviate used to calculate the 95th percentile from a lognormal distribution of blood lead concentrations.

$R_{fetal/maternal}$ = Constant of proportionality between the fetal blood lead concentration at birth and maternal blood lead concentration (dimensionless).

Blood lead concentrations in women of child-bearing age exposed to lead in site soils are estimated using Equation 2:

$$PbB_{adult,central} = PbB_{adult,0} + \frac{(PbS)(BKSF)(IR_s)(AF_s)(EF_s)}{AT} \qquad \text{(Eq. 2)}$$

Where:

$PbB_{adult, central}$ = Central estimate of blood lead concentrations (µg/dL) in women of child-bearing age that have site exposures to lead in soil.

$PbB_{adult, 0}$ = Typical blood lead concentration (µg/dL) in women of child-bearing age in the absence of exposures to the site.

PbS = Appropriate average soil lead concentration (e.g., upper confidence limit [UCL] on the arithmetic mean [see Appendix A]; microgram per gram [µg/g], which is equivalent to mg/kg).

BKSF = Biokinetic slope factor (quasi-steady state) relating increase in typical adult blood lead concentration to average daily lead uptake (µg/dL blood lead increase per µg/day lead uptake)

Ir_s = Intake rate of soil, including both outdoor soil and indoor soil-derived dust (grams per day [g/day]).

AF_s = Absolute gastrointestinal absorption fraction for ingested lead in soil and lead in dust derived from soil (dimensionless).

EF_s = Exposure frequency for contact with assessed soils and/or dusts derived in part from these soils (days of exposure during the averaging period); may be taken as days per year for continued, long-term exposure.

AT = Averaging time: the total period during which soil contact may occur; 365 days/year for continued, long-term exposures.

As noted in Equation 2, background sources of lead exposure (i.e., lead in food, drinking water, and soil/dust) are accounted for in the model. Per USEPA (1996c), this model is based on the assumption of quasi-steady-state biokinetics, and therefore, it is recommended that the model not be applied to scenarios in which the exposure frequency

(EF_s) is less than one day per week. USEPA (1996c) states that an approximate 90-day exposure duration is necessary to achieve quasi-steady state blood lead concentrations.

Although limited information is available on the direct health effects of elevated blood lead concentrations in fetuses and neonates, the range of adverse health effects in infants and children is well established (Agency for Toxic Substances and Disease Registry [ATSDR], 1993). USEPA (1994a) has sought to minimize childhood risk of elevated blood lead concentrations by establishing cleanup goals that limit the risk of exceeding a specified blood lead level (e.g., 10 µg/dL) to 5 percent. Therefore, the 95th percentile ($PbB_{fetal, 0.95}$) is selected as the percentile of interest on the fetal blood lead concentration distribution.

The TRW Adult Lead Model also provides algorithms for deriving non-residential risk-based remediation goals for lead in soils. Equation 1 above can be rearranged to reflect a risk-based goal for the central estimate of blood lead concentrations in adult women, as shown in Equation 3:

$$PbB_{adult,central,goal} = \frac{PbB_{fetal,0.95,goal}}{(GSD_{i,adult}^{1.645})(R_{fetal/maternal})} \quad \text{(Eq. 3)}$$

Where:

$PbB_{adult, central,goal}$ = Goal for central estimate of blood lead concentrations (µg/dL) in adults (i.e., women of child-bearing age) that have site exposures to lead in soil. The goal is intended to ensure that $PbB_{fetal,0.95,goal}$ does not exceed 10 µg/dL.

$PbB_{fetal, 0.95, goal}$ = Goal for the 95th percentile blood lead concentration (µg/dL) among fetuses born to women having exposures to lead in soils. This is interpreted to mean that there is a 95-percent likelihood that a fetus, in a woman who experiences such exposures, would have a blood lead concentration ≤ $PbB_{fetal, 0.95, goal}$

$GSD_{i, adult}$ = Estimated value of the individual geometric standard deviation (dimensionless); the GSD among adults (i.e., women of child-bearing age) that have exposures to similar onsite lead concentrations, but that have non-uniform response (intake, biokinetics) to site lead and non-uniform offsite lead exposures. The exponent, 1.645, is the value of the standard normal deviate used to calculate the 95th percentile from a lognormal distribution of blood lead concentrations.

$R_{fetal/maternal}$ = Constant of proportionality between fetal blood lead concentration at birth and maternal blood lead concentration (dimensionless).

Per USEPA (1996c), the soil lead concentration associated with a given exposure scenario and $PbB_{adult,central,goal}$ can be calculated by rearranging Equation 3 and substituting $PbB_{adult,central,goal}$ for $PbB_{adult,central}$, as shown in Equation 4:

$$\text{risk - based remediation goal} = \frac{(PbB_{adult,central,goal} - PbB_{adult,0})(AT)}{(BKSF)(IR_s)(AF_s)(EF_s)} \quad \text{(Eq. 4)}$$

Where:

$PbB_{adult,\ central,goal}$	=	Goal for central estimate of blood lead concentrations (µg/dL) in adults (i.e., women of child-bearing age) that have site exposures to lead in soil. The goal is intended to ensure that $PbB_{fetal,0.95,goal}$ does not exceed 10 µg/dL.
$PbB_{adult,\ 0}$	=	Typical blood lead concentration (µg/dL) in adults (i.e., women of child-bearing age) in the absence of exposures to the site.
AT	=	Averaging time: the total period during which soil contact may occur; 365 days/year for continued long-term exposures.
BKSF	=	Biokinetic slope factor (quasi-steady state) relating the increase in typical adult blood lead concentration to average daily lead uptake (µg/dL blood lead increase per µg/day lead uptake)
Ir_s	=	Intake rate of soil, including both outdoor soil and indoor soil-derived dust (g/day).
AF_s	=	Absolute gastrointestinal absorption fraction for ingested lead in soil and lead in dust derived from soil (dimensionless).
Ef_s	=	Exposure frequency for contact with assessed soils and/or dusts derived in part from these soils (days of exposure during the averaging period); may be taken as days/year for continued, long-term exposure.

B.2.1.2 Adult Lead Model Parameter Selection and Justification

A discussion of each parameter used in the TRW Adult Lead Model is provided below.

95th Percentile Fetal Blood Lead Concentration Goal ($PbB_{fetal,0.95,goal}$). The recommended value for $PbB_{fetal,\ 0.95,\ goal}$ is 10 µg/dL and is based on current Office of Solid Waste and Emergency Response (OSWER) guidance, which calls for the establishment of cleanup goals to limit residential childhood risk of exceeding 10 µg/dL to 5-percent (USEPA, 1994a). TRW (USEPA, 1996c) has recommended applying a similar 95th-percentile goal to the protection of fetuses carried by women who experience nonresidential exposures to lead (i.e., the goal is intended to ensure that the likelihood of a blood lead concentration exceeding 10 µg/dL in the fetus would be less than a 5-percent chance of occurence).

Individual Blood Lead Geometric Standard Deviation (GSD_i). GSD_i is a measure of the inter-individual variability in blood lead concentrations in a population of nonresidential adult female receptors exposed to the same environmental lead levels.

TRW (USEPA, 1996c) estimated that 1.8 to 2.1 is a plausible range for GSD_i, based on a preliminary analysis of blood lead concentration data collected in the Third National Health and Nutrition Examination Survey (NHANES III) Phase 1 (1988 to 1991) for women ages 17 to 45 years (USEPA, 1996c). TRW reported GSD_i values for non-Hispanic white, non-Hispanic black, and Mexican American women of 1.89, 1.98, and 2.10, respectively (USEPA, 1996c). Ideally, the value for GSD_i used in the TRW Adult Lead Model should be estimated for the population of concern at the site. However, as is often the case for the potentially exposed population, a site-specific GSD_i calculated from measured blood lead concentrations in an exposed population is not available. In the absence of site-specific data, TRW recommends selecting a value from the proposed range of values (i.e., 1.8 to 2.1) based on site-specific demographic information for the potentially exposed population at the site (USEPA, 1996c). If potentially exposed industrial workers at the site consist primarily of civilian employees, site-specific Census Bureau data (http://www.census.gov) may be used to estimate the demographic characteristics of potentially exposed receptors. An example of site-specific demographic characteristics is shown in Table B.1

TABLE B.1
EXAMPLE OF SITE-SPECIFIC DEMOGRAPHIC CHARACTERISTICS [a/]

City	Population				
	Total	Non-Hispanic White	Non-Hispanic Black	Mexican American	Other
Example City	935,933	339,115	63,260	520,282	13,276
Fraction of Total:	1.00	0.36	0.07	0.56	0.01

[a/] Example from US Census Bureau (http://www.census.gov).

Based on the information presented in Table B.1, a site-specific GSD_i can be estimated using Equations 5 (USEPA, 1996c):

$$Weighted\ GSD_i = \frac{[(GSD_i)_{NHW} \bullet F_{NHW}] + [(GSD_i)_{NHB} \bullet F_{NHB}] + [(GSD_i)_{MA} \bullet F_{MA}]}{F_{NHW} + F_{NHB} + F_{MA}} \quad \text{(Eq. 5)}$$

Where:

Weighted GSD_i = GSD_i weighted average based on site-specific demographics and the NHANES III Phase 1 summary data presented in USEPA (1996c).

$(GSD_i)_{NHW}$ = GSD_i of 1.9 for non-Hispanic white females, ages 17 through 45 years, as summarized in USEPA (1996c).

$(GSD_i)_{NHB}$ = GSD_i of 2.0 for non-Hispanic black females, ages 17 through 45 years, as summarized in USEPA (1996c).

$(GSD_i)_{MA}$ = GSD_i of 2.1 for Mexican American females, ages 17 through 45

years, as summarized in USEPA (1996c).

F_{NHW} = Site-specific fraction of non-Hispanic white females, ages 17 through 45 years for the potentially exposed population.

F_{NHB} = Site-specific fraction of non-Hispanic black females, ages 17 through 45 years for the potentially exposed population.

F_{MA} = Site-specific fraction of Mexican American females, ages 17 through 45 years for the potentially exposed population.

Fetal/Maternal Blood Lead Concentration Ratio ($R_{fetal/maternal}$). This parameter describes the relationship between maternal and fetal blood lead concentrations. TRW (USEPA, 1996c) recommends a default value of 0.9 based on studies correlating umbilical cord and maternal blood lead concentrations.

Baseline Blood Lead Concentration ($PbB_{adult,0}$). $PbB_{adult,0}$ is intended to represent a reasonable estimate of background blood lead concentrations in women of child-bearing age who are not exposed to lead-contaminated soil or dust at the site. Background exposures result from exposures to lead in food, drinking water, soil and/or dust, and ambient air. Ideally, the value for $PbB_{adult,0}$ used in the TRW Adult Lead Model should be estimated for the population of concern at a site. This would require data on blood lead concentrations in a representative sample of adult women not exposed to lead in site soils and/or dusts; these data often are not available. In the absence of site-specific data, USEPA (1996c) recommends extrapolating $PbB_{adult,0}$ from estimates for other surrogate populations that would be expected to have a similar $PbB_{adult,0}$ distribution as that of the population of concern. The TRW summarized geometric mean $PbB_{adult,0}$ results from Phase 1 of the NHANES III study for three ethnic and racial categories (USEPA, 1996c); these results are summarized in Table B.2.

TABLE B.2
$PbB_{adult,0}$ AMONG DIFFERENT POPULATIONS OF WOMEN AGES 20-49

Population	Geometric Mean (µg/dL)
Non-Hispanic white women	1.7
Non-Hispanic black women	2.2
Mexican American women	2.0

TRW (USEPA, 1996c) recommends using the estimates shown in Table B.2 in combination with regional demographic characteristics (Table B.1) to estimate the most appropriate $PbB_{adult,0}$ for use in the TRW Adult Lead Model. A site-specific weighted $PbB_{adult,0}$ can be calculated as shown in equation 6.

$$Weighted\ \ PbB_{adult,0} = \frac{\left[(PbB_{adult,0})_{NHW} \bullet F_{NHW}\right] + \left[(PbB_{adult,0})_{NHB} \bullet F_{NHB}\right] + \left[(PbB_{adult,0})_{MA} \bullet F_{MA}\right]}{F_{NHW} + F_{NHB} + F_{MA}} \quad \text{(Eq. 6)}$$

Where:

Weighted $PbB_{adult,0}$ = $PbB_{adult,0}$ weighted average based on site-specific demographics and the NHANES III Phase 1 summary data presented in USEPA (1996c).

$(PbB_{adult,0})_{NHW}$ = $PbB_{adult,0}$ of 1.7 for non-Hispanic white females as summarized in USEPA (1996c).

$(PbB_{adult,0})_{NHB}$ = $PbB_{adult,0}$ of 2.2 for non-Hispanic black females as summarized in USEPA (1996c).

$(PbB_{adult,0})_{MA}$ = $PbB_{adult,0}$ of 2.0 for Mexican American females as summarized in USEPA (1996c).

F_{NHW} = Site-specific fraction of non-Hispanic white females for the potentially exposed population.

F_{NHB} = Site-specific fraction of non-Hispanic black females for the potentially exposed population.

F_{MA} = Site-specific fraction of Mexican American females for the potentially exposed population.

Biokinetic Slope Factor (BKSF). The BKSF parameter correlates the blood lead concentration to lead uptake. Per USEPA (1996c), the recommended default value is 0.4 based on data relating tap water lead concentrations to blood lead concentrations.

Daily Soil Ingestion Rate (IR_s). The TRW (USEPA, 1996c) recommends a default value of 0.05 g/day as a reasonable estimate for daily soil ingestion from all occupational exposure scenarios, including indoor dust, resulting from non-contact activities (i.e., nonintrusive activities).

Exposure Frequency (EF_s). The TRW recommends a default value of 219 days/yr for nonresidential exposure to lead in soil (USEPA, 1996c). This value is the same as the CT occupational EF recommended by USEPA (1993c) and is based on 1991 data from the Bureau of Labor Statistics. However, TRW also recognizes that nonresidential EFs significantly less than 219 days/yr frequently are encountered. Therefore, TRW recommends that site-specific EF data be considered in evaluating whether the default value is applicable to the population of concern (USEPA, 1996c).

Soil Lead Absorption Factor (AF_s). The AF_s parameter is the fraction of lead in soil that is ingested daily and is absorbed by the gastrointestinal tract. The AF_s parameter is a product of the absorption factor for soluble lead ($AF_{soluble}$) and the relative bioavailability of lead in soil compared to soluble lead ($RBF_{soil/soluble}$) as shown in Equation 7:

$$AF_s = AF_{soluble} \bullet RBF_{soil/soluble} \quad \text{(Eq. 7)}$$

There is a significant body of research and literature associated with the bioavailability of lead to humans. Although information on the bioavailability of lead in soils at firing-range sites is sparse, observations and principles about bioavailability developed for other sources of lead contamination can be applied to this type of site.

In the absence of site-specific data, the TRW recommends a default AF_s of 0.12 based on the assumption that $AF_{soluble}$ is 0.2 and $RBF_{soil/soluble}$ is 0.6 (USEPA, 1996c). However, the TRW states that site-specific bioavailability data are highly desirable because $RBF_{soil/soluble}$ is expected to vary significantly dependent upon lead speciation and particle sizes, both of which may vary from site-to-site (USEPA, 1996c). A site-specific AF_s can be developed based on an assumed $AF_{soluble}$ of 0.2 (the TRW-recommended default value) and a site-specific average $RBF_{soil/soluble}$ factor. Refer to Appendix C for a discussion of methods that can be used to develop site-specific $RBF_{soil/soluble}$ factors.

A number of factors affect the solubility and bioavailability of lead, as discussed by USEPA (1994c and 1996c) and Hrudey *et al.* (1996). These factors include, but are not limited to, the following:

- The effect of food on lead bioavailability;
- The variability in lead intake;
- The effect of the chemical form and particle size on lead bioavailability;
- Differences in sensitivities to the adverse health effects from lead exposure in children and adults (children are significantly more sensitive); and
- The effect of deficiencies in calcium, iron, zinc, copper, phosphorus, vitamin D, dietary lipids, and certain milk components (particularly lactose) on lead absorption.

Bioavailability of metallic lead has been shown to decrease with increasing particle size (Barltrop and Meek, 1979). There also is evidence to suggest that smaller soil particles (e.g., <100-250 µm) are more likely to be incidentally ingested than larger particles because the particles adhere more readily to the skin (Duggan *et al.*, 1985; Bornshine, *et al.*, 1987; Driver *et al.*, 1989; Sheppard and Evenden, 1994; Duff and Kissel, 1996; and Kissel *et al.*, 1996a). A conservative value of 250 µm in diameter is applied as an upper limit of bioavailable particle size by researchers at the University of Colorado (Drexler, 1997). Lead bioavailability also is expected to vary dependent on the chemical species (from most to least bioavailable): lead carbonate > lead oxides > native or elemental lead > manganese/lead or iron/lead oxides and lead phosphates.

Currently, USEPA's (1994c and 1996c) lead exposure models do not accommodate input parameters for lead particle size or speciation. However, site-specific data on lead concentrations in the <250 µm particle size soil fraction can be used in the model. In addition, *in vitro* bioavailability and speciation of lead in the <250 µm soil fractions can

be determined to provide qualitative support to the *in-vitro* bioavailability results. Refer to Appendix C for methods to evaluate lead particle size and speciation in firing-range soils.

B.2.2 Child Blood Lead Levels

The methodology used to estimate child blood lead concentrations at Rifle Range B is briefly discussed in this subsection, followed by a discussion of parameter selection and justification.

B.2.2.1 Algorithms for Estimating Child Blood Lead Concentrations

Potential risk to a future child resident from lead contamination in soil can be estimated using the USEPA's (1994c) *Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children*. The IEUBK model estimates blood-lead levels in children exposed to environmental sources of lead using site-specific data and/or default values for lead in each medium of concern. The model integrates exposure to lead in soil, air, drinking water, dust, diet, and/or lead-based paint for individual age groups. Age-specific mean blood-lead levels are computed using the biokinetic model, and the predicated uptakes (over time) are summed to estimate the distribution of blood-lead levels in children. From this distribution, the model calculates the probability that children's blood lead concentrations will exceed a specified level of concern. USEPA (1994a) has sought to minimize childhood risk of elevated blood lead concentrations by establishing cleanup goals that limit the risk of exceeding 10 µg/dL (i.e., level of concern) blood lead to 5 percent. Refer to the USEPA (1994c) IEUBK Guidance Manual for a detailed discussion of the algorithms used to estimate risk to a future child resident from lead contamination in soil.

B.2.2.2 IEUBK Model Parameter Selection and Justification

Per USEPA (1994c), site-specific parameters can be incorporated into the IEUBK model. The IEUBK Guidance Manual (USEPA, 1994a) provides a worksheet that can be used to identify input parameters and select appropriate values. The relevant IEUBK input parameters needed to assess potential risk to a future child resident exposed to lead in soils are listed in Table B.3. Justification for the IEUBK default input parameter values is provided in the USEPA (1994c) IEUBK Guidance Manual. Site-specific data for the parameters discussed below may be readily available for firing range sites and can be incorporated into the IEUBK model. However, when modifying these parameters and/or other parameters used in the IEUBK model, it is important to consider the level of effort necessary to obtain and document any changes to USEPA (1994c) recommended defaults.

Outdoor Air Lead Concentration. A site-specific monitored background lead air concentration may be available from the USEPA (2000a) Aerometric Information Retrieval System (AIRS) database. A site-specific outdoor air concentration would replace the IEUBK default value of 0.1 µg/m^3, which is based on a typical 1993 urban estimate.

TABLE B.3
IEUBK INPUT PARAMETERS FOR FUTURE CHILD RESIDENTS

Input Parameter
Outdoor air lead concentration ($\mu g/m^3$)
Ratio of indoor to outdoor air lead concentration (%)
Time outdoors (hr/day)
Ventilation rate (m^3/day)
Lung absorption (%)
Dietary lead intake (µg Pb/day)
Lead concentration in drinking water (µg/L)
Drinking water ingestion rate (L/day)
Lead concentration in soil (µg/g)
Lead concentration in dust (µg/g)
Soil ingestion as percent of total soil and dust ingestion
Soil/dust ingestion by year (g/day)
Ratio of dust lead concentration to soil lead concentration
Ratio of dust lead concentration to outdoor air lead concentration
Gastrointestinal Bioavailability of Lead in Diet, Drinking Water, and Dust
Gastrointestinal Bioavailability of Lead in Soil
Fraction of lead absorbed passively at high intake
Mother's blood lead level at time of birth
Geometric standard deviation for blood lead, GSD
Blood lead level of concern, or cutoff
Iteration time step for numerical integration

Lead Concentration in Drinking Water. Base- or community-specific water lead data may be available. In the absence of relevant drinking water lead data, USEPA (1994c) recommends using a default value of 4 µg/L.

Lead Concentration in Soil. Per USEPA (1994c), the arithmetic mean concentration of lead in soil should be used in the IEUBK model. The surface soil interval (e.g., 0 to 0.5 foot below-ground-surface [bgs]) typically is considered the most likely exposure interval for a future child resident.

Gastrointestinal Bioavailability of Lead in Soil. The relative bioavailability of lead in soil compared to soluble lead may be estimated as described in Section B.2.1.2. These in-vitro bioavailability results then can be used to estimate the IEUBK parameter for gastrointestinal bioavailability of lead in soil.

B.2.3 Non-Lead COPCs

The methodology for estimating potential exposure to non-lead COPCs in site soils differs from the approach used to evaluate potential risk from exposure to lead. The following exposure pathways are typically evaluated for non-lead COPCs:

- Incidental ingestion of soil,
- Inhalation of particulates/fugitive dust, and
- Dermal contact with soils.

The equations that are used to quantify non-lead COPC risks and hazards to potential human receptors for each of these exposure routes are described below. A discussion of the exposure parameters also is provided.

B.2.3.1 Incidental Soil Ingestion

Per USEPA (1989a), potential exposure via incidental ingestion of soil is estimated using the following equation.

$$\text{Intake} = \frac{(C_{soil})(IR_{soil})(EF)(ED)(FI)(CF)}{(BW)(AT)(365 days/year)}$$

where:

Intake	=	The amount of COPC at the exchange boundary (mg/kg-day);
C_{soil}	=	COPC concentration in soil (i.e., EPC) (mg/kg);
IR_{soil}	=	Soil ingestion rate (mg/day);
EF	=	Exposure frequency (days/year);
ED	=	Exposure duration (years);
FI	=	Fraction contaminated soil ingested (unitless);
CF	=	Conversion factor (10^{-6} kg/mg);
BW	=	Body weight (kg);
AT_c	=	Averaging time for carcinogens (years); and
AT_n	=	Averaging time for noncarcinogens (years).

B.2.3.2 Dermal Contact with Soil

Dermal exposure to contaminants in soil is estimated using the methodology and algorithms described in *Dermal Exposure Assessment: Principles and Applications* (USEPA, 1992e), *Exposure Factors Handbook, Volume I, General Factors* (USEPA, 1997d), and from literature sources as cited. The dermally absorbed dose resulting from contact with contaminants in soil is calculated per USEPA (1992e) using the following algorithm.

$$DAD = \frac{(DA_{event})(EV)(ED)(EF)(ET)(SA)}{(BW)(AT)(365 days/year)}$$

Where:

DAD = Dermally absorbed dose (mg/kg-day);

DA_{event} = Absorbed dose per event per area of skin exposed (mg/cm²-event);

EV = Event frequency (events/day);

ED = Exposure duration (years);

EF = Exposure frequency (days/year);

ET = Fraction of exposure frequency in contact with soil (unitless);

SA = Skin surface area available for contact (cm²);

BW = Body weight (kg); and

AT = Averaging time (years).

DA_{event} (mg/cm²-event) for contaminants in soil is calculated using the following equation (USEPA, 1992e).

$$DA_{event} = (C_{soil})(AF)(DAF)(CF)$$

Where:

DA_{event} = Absorbed dose per event per area of skin exposed (mg/cm²-day);

C_{soil} = Contaminant concentration in soil (mg/kg);

AF = Soil-to-skin adherence factor (mg/cm²-day);

DAF = Dermal absorption fraction (unitless); and

CF = Conversion factor (10^{-6} kg/mg).

B.2.3.3 Inhalation of Volatiles/Particulates from Soil

Recent USEPA (1996b) guidance does not recommend estimating intakes (i.e., mg/kg-day) for the air inhalation pathway. Rather, risks and hazards are determined by comparing estimated volatile/particulate air concentrations (adjusted for exposure frequencies, exposure durations, and exposure times) with inhalation toxicity values.

Methods for estimating concentrations of COPCs volatilized (e.g., PAHs) from soil or entrained in airborne dusts (e.g., metals) are described in this subsection. Refer to the Section B.4 for specific methods used to estimate risks/hazards for the air inhalation pathway.

EPCs for COPCs Volatilized from Soil. Although likely insignificant, it may be necessary to estimate volatilization of PAH COPCs. Per USEPA (1996b), EPCs for organic COPCs volatilized from surface soil into outdoor air are based on the soil EPCs and estimated using the following equation:

$$C_{Air} = \frac{C_{Soil}}{VF}$$

where:

C_{Air} = COPC concentration in air at the exposure point (mg/m^3);

C_{Soil} = COPC EPC in soil (mg/kg); and

VF = Chemical-specific volatilization factor (m^3/kg).

The soil-to-air volatilization factor (VF) is used to define the relationship between the concentrations of COPCs in soil and the flux of volatilized COPCs to air. VFs are calculated using methods described in the *Soil Screening Guidance: Technical Background Document* (USEPA, 1996b). Calculation of VF involves use of site-specific, chemical-specific, and default factors. The USEPA (1996b) guidance provides default source concentration terms (called Q/C terms) based on meteorological conditions specific to 29 locations throughout the country and the size of the contaminant source. Per USEPA (1996b), a Q/C value best representing the area's size and meteorological conditions at/near the site should be used in the VF calculation.

EPCs for COPCs in Fugitive Dust. Per USEPA (1996b), EPCs for metal COPCs in airborne fugitive dust are based on soil EPCs and estimated using the following equation.

$$C_{air} = \frac{C_{soil}}{PEF}$$

where:

C_{Air} = COPC concentration in air at the exposure point (mg/m^3);

C_{Soil} = COPC EPC in soil (mg/kg); and

PEF = Particulate emission factor (m^3/kg).

The particulate emission factor (PEF) relates the concentration of the soil COPC to the concentration of dust particles in the air. This calculation addresses dust generated from open sources, which is termed "fugitive" because it is not discharged into the atmosphere

in a confined flow. PEF calculations include the Q/C term specific to the sites' sizes and meteorological conditions.

B.2.3.4 Exposure Assumptions

The purpose of this section is to provide a discussion of the parameters that are used in the non-lead COPC exposure algorithms. Commonly used exposure parameters, brief statements on the justification for the parameter values, and references for these values are provided in Table B.4. Most exposure parameters have a range of values. Exposure parameters should be selected with the intent that the combination of variables for a given exposure pathway will result in an estimate of the reasonable maximum exposure (RME) for that pathway. The RME is defined as the highest exposure that reasonably could be expected to occur for a given exposure pathway at a site, and in practice is estimated by combining high-end (e.g., 90th to 95th percentile) values for some but not all exposure parameters (USEPA, 1989a, 1992b, 1993c). As discussed in *Guidance on Risk Characterization for Risk Managers and Risk Assessors* (USEPA, 1992b), the most sensitive parameters should be identified and high-end values should be used for one or more of those variables. Studies of the compounding of conservatism in probabilistic risk assessments show that setting as few as two factors at RME levels or high end (e.g., near the 90th percentile), while the remaining variables are set at less conservative, typical or "central tendency" (CT) values results in a product of all input variables at an approximate RME level (e.g., 99th percentile value) (Cullen, 1994). Central tendency/average values should be used for all other exposure parameters.

Generally, contact rate, exposure frequency, and exposure duration are the most sensitive parameters (i.e., likely to drive exposure estimates). When statistical data are available, 90th or 95th percentile values are selected for exposure duration. If distributions are not available (e.g., for children), high-end estimates are made using best professional judgement. Typically, distributional data are not available for exposure frequency, therefore, high-end estimates are used based on available site-specific information and best professional judgement. The justification for each parameter is discussed in the following subsections.

Exposure-Point Concentrations. EPCs generally are estimates of the arithmetic average of the concentrations that may be contacted over the exposure period. A detailed discussion of the EPCs is provided in Appendix A.

Body Weight. According to USEPA's (1997d) *Exposure Factors Handbook* (hereafter referred to as EFH), the average body weight for all adults (male and female) is 71.8 kg (adapted from the National Center of Health Statistics). This value represents the average body weight for male and female adults between the age of 18 and 75 years. The value of 71.8 kg has been rounded to 70 kg for use as the adult body weight to account for the estimated clothing weight (0.09-0.28 kg) and to be consistent with the body weight used by USEPA (2000b) in the derivation of cancer slope factors and unit risks. The body weight value represents the average body weight over the exposure duration. An average body weight value is used per USEPA (1997d) recommendation, but also because body weight is correlated with other exposure parameters (e.g., intake and skin surface area).

TABLE B.4
SUMMARY OF EXPOSURE VARIABLES FOR SOIL PATHWAYS

Exposure Variable/ Recommended value	Receptor	Rationale	Reference
GENERAL (i.e., applies to all soil exposure pathways)			
BW = Body weight			
70 kg	All adult receptors	Standard reference weight for adults	USEPA 1991a
15 kg	All child receptors	Standard reference weig ht for children	USEPA 1991a
EF = Exposure frequency			
350 days/year	RME-Adult and Child residents	Assume year-round exposure with one 2-week vacation	USEPA 1991a, 1993a
234 days/year	CT – Adult and Child residents	Mean for exposure to soil by residents	USEPA, 1991a
Site-specific	RME & CT - All adult workers	Site-specific	Site-specific
ED = Exposure duration			
30 years or site-specific	RME-Adult resident	Upper bound time at one residence (30 years) or value may be adjusted downward based on site-specific information	USEPA, 1989, 1993a or site-specific
9 years or site-specific	CT-Adult resident	Average time at one residence (30 years) or value may be adjusted downward based on site-specific information	USEPA, 1989, 1993a or site-specific
6 years	RME & CT-Child resident	Standard exposure duration (RME & CT) at one residence	USEPA 1989
AT = Averaging time			
70 years (carcinogens)	All receptors	Conventional human lifespan (intakes averaged over lifespan)	USEPA 1989
ED (noncarcinogens)	All receptors	Intakes averaged over the exposure duration	USEPA 1989

TABLE B.4 (CONTINUED)
SUMMARY OF EXPOSURE VARIABLES FOR SOIL PATHWAYS

Exposure Variable/ Recommended value	Receptor	Rationale	Reference
INGESTION			
IR = sediment ingestion rate			
50 mg/day	RME-Nonintrusive worker and Adult resident	Standard default soil ingestion rate	USEPA, 1997b
25 mg/day	CT-Nonintrusive worker and Adult resident	One-half RME value	Best Judgement
100 mg/day	RME-Adult intrusive worker	Two-times the USEPA (1997b) recommended value for adults	Best Judegement
50 mg/day	CT-Adult intrusive worker	Assume equivalent to RME nonintrusive soil ingestion rate	Best Judgement
200 mg/day	RME-Child resident	Standard default soil ingestion rate	USEPA, 1993a, 1997b
100 mg/day	CT-Child resident	Standard default soil ingestion rate	USEPA, 1993a
FI = Fraction contaminated soil ingested			
1 (unitless)	All receptors	Assume soil ingestion occurs on-site	Conservative estimate
DERMAL CONTACT			
ET = Fraction of EF in contact with soil			
1 (unitless)	All receptors	Assume soil contact occurs on-site	Conservative estimate

TABLE B.4 (CONTINUED)
SUMMARY OF EXPOSURE VARIABLES FOR SOIL PATHWAYS

Exposure Variable/ Recommended value	Receptor	Rationale	Reference
SA = Surface Area 3280 cm^2	RME & CT-Adult workers	Assume worker wearing short-sleeved shirt, long pants, and shoes; therefore, exposed body parts are the hands, forearms, and head. Body part-specific SAs summed. RME=CT because SA must correlate with BW.	USEPA, 1997b
5650 cm^2	RME & CT-Adult residents and Adult recreator	Assume receptors wearing short-sleeved shirt, shorts and shoes ; therefore, exposed body parts are the head, hands, forearms, and lowerlegs. Body part-specific SAs summed. RME=CT because SA must correlate with BW.	USEPA, 1997b
2830 cm^2	RME & CT-Child residents and Child recreator	Assume child wearing short-sleeved shirt, shorts, and shoes or no shoes; therefore, exposed body parts are the head, hands, forearms, lowerlegs, and feet. Body part-specific SAs summed. RME=CT because SA must correlate with BW.	USEPA, 1997b

TABLE B.4 (CONTINUED)
SUMMARY OF EXPOSURE VARIABLES FOR SOIL PATHWAYS

Exposure Variable/ Recommended value	Receptor	Rationale	Reference
AF = Soil adherence factor			
0.04 mg/cm^2	RME - Adult nonintrusive worker	Activity and body part-specific weighted based on exposed body parts.	USEPA, 1997b
0.02 mg/cm^2	CT - Adult nonintrusive worker		USEPA, 1997b
0.2 mg/cm^2	RME - Adult intrusive worker		USEPA, 1997b
0.04 mg/cm^2	CT - Adult intrusive worker		USEPA, 1997b
0.07 mg/cm^2	RME - Adult resident		USEPA, 1997b
0.01 mg/cm^2	CT - Adult resident		USEPA, 1997b
0.2 mg/cm^2	RME - Child resident		USEPA, 1997b
0.04 mg/cm^2	CT - Child resident		USEPA, 1997b
DAF = Dermal soil absorption factor (unitless)	All receptors	Chemical-specific	USEPA, 1992a and literature
OAF = Gastrointestinal oral absorption factor (unitless)	All receptors	Chemical-specific	Literature
INHALATION OF DUST FROM SOIL			
ET = Fraction of EF breathing contaminated outdoor air Site-specific (unitless)	All receptors	Site-specific	Site-specific
PEF = Particulate emission factor Site-specific	All receptors	Site-specific	Site-specific

An average body weight of 15 kg is used for children. The time-weighted average for boys and girls, ages six months to six years presented in EFH (USEPA, 1997d) is 15.5 kg and can be calculated by time-weighting the mean body weight for boys and girls listed in Tables 7-6 and 7-7. The value of 15.5 kg has been rounded to 15 kg to account for the estimated clothing weight (0.09-0.28 kg) and is consistent with the USEPA (1993c) recommended body weight for children.

Exposure Frequency. Exposure frequency is site-specific based on expected activities for each of the receptors. Therefore, national data on the distribution of exposure frequencies are not available. Consistent with the RME approach described above, high-end estimates of exposure frequencies should be used for each of the receptors evaluated in the HRA.

Exposure frequencies for non-residential workers should be site-specific based on current and/or reasonably expected future land use. The standard high-end default residential exposure frequency of 350 days/year recommended by USEPA (1991b, 1993c) is used at sites where there is the potential for reasonable future land to be residential. This value is based on the assumption that the future receptor will be exposed to contaminants on a daily basis, except during a two-week period when they are away from the home (e.g., on vacation) (USEPA, 1991b, 1993c).

Exposure Duration. The standard high-end default occupational exposure duration of 25 years recommended by USEPA (1991b, 1993c) is used for nonintrusive workers. This value is based on the 95th percentile for the number of years worked at the same location as reported by the U.S. Bureau of Labor Statistics (1990). However, this parameter may be adjusted downward based on site-specific data (e.g., number of years an enlisted person is stationed at the base).

National statistics are available for residential occupancy periods based on U.S. Bureau of Census data as summarized in USEPA's (1997d) EFH. The standard residential high-end default exposure duration of 30 years recommended by the USEPA (1997d) is used for adult residents. This value is based on the 90th percentile value from the Census data for the time an individual spends at a single resident. However, the exposure duration for an adult resident may be adjusted downward based on site-specific data (e.g., number of years residing in military housing). Although there are no statistical data available on childhood residential occupancy periods, it is assumed that a child (0-6 years old) resides at the 90th percentile adult resident's home and therefore, the exposure duration is 6 years.

Averaging Time. The averaging time selected depends on the type of toxic effect being assessed (USEPA, 1989a). Exposure is averaged over an individual's lifetime for carcinogens and the period of exposure (i.e., the exposure duration) for noncarcinogens. Although current data suggest that 75 years would be an appropriate value to reflect the average life expectancy of the general population (USEPA, 1997d), an averaging time of 70 years is used to be consistent with use of 70 years in the derivation of USEPA (2000b) cancer slope factors and unit risks. For noncarcinogens, the averaging time is equal to the exposure duration for each of the receptors evaluated.

Contact Rates. Contact rates reflect the amount of contaminated medium contacted per unit time or event. As discussed previously, exposure parameters are selected with the intent that the combination of variables for a given exposure pathway will result in an estimate of the RME. To avoid estimates that likely will be outside the distribution of actual exposure, average contact rates are paired with high-end exposure frequencies and durations.

Incidental soil ingestion rates depend on the receptor being evaluated. The standard adult estimate of 50 mg/day recommended by USEPA (1997d) is used for nonintrusive workers and adult residents. Per USEPA (1997d), "50 mg/day still represents a reasonable central estimate of adult soil ingestion and is the recommended value in this handbook."

A high-end estimate of 100 mg/day may be used as the soil ingestion rate for an intrusive (e.g., construction) worker. This value differs from the value of 480 mg/day derived by Hawley (1985) for adults engaged in short-term outdoor activities. The value of 480 mg/day value was derived using a semi-qualitative approach with assumptions about soil/dust levels on hands and mouthing behavior; no supporting measurements were made. The Hawley (1985) value was calculated using the following assumptions: 1) adults working outside have a soil-to-skin loading rate of 3.5 mg/cm^2 (50 μm thick monolayer of soil); and 2) adults ingest the soil on approximately one-half of the inside surface area of the fingers and thumbs twice per day. However, using actual soil adherence studies conducted on construction workers, Holmes *et al.* (1999) measured hand soil adherence values of 0.14-0.44 mg/cm^2, which are significantly less than the value of 3.5 mg/cm^2 assumed by Hawley. Using the Hawley (1985) approach and replacing the theoretical value of 3.5 mg/cm^2 with the maximum measured value of 0.44 mg/cm^2 results in a more realistic soil ingestion estimate of 60 mg/day. Given the uncertainties associated with the other assumptions made by Hawley (1985), a soil ingestion rate of 100 mg/day is recommended for intrusive workers, which is twice the recommended value for adults (USEPA, 1997d).

The default high-end central tendency soil ingestion estimate of 200 mg/day recommended by USEPA (1991b, 1993c) for children 0- to 6-years old is used in the HRAs. Although USEPA (1997d) currently lists 100 mg/day as the recommended mean soil ingestion rate for children (see Table 4-23 in the EFH), they also footnote this value stating that, "200 mg/day may be used as a conservative estimate of the mean."

Skin Surface Areas. The skin surface area (SA) parameter describes the amount of skin exposed to the contaminated media. The amount of skin exposed depends upon the exposure scenario. Clothing is expected to limit the extent of the exposed SA in cases of soil contact. All SA estimates use 50th percentile values to correlate with the average body weights. This is done to prevent inconsistent parameter combinations as body weight and SA are dependent variables. Body part-specific SAs are calculated using the body part-specific SAs listed in USEPA (1997d) and are shown in Table B.5.

TABLE B.5
BODY PART-SPECIFIC SURFACE AREA CALCULATIONS

CHILDREN

Fraction of Total SA (unitless)[a]

Age (y)	Head	Face[b]	Arms	Forearms[c]	Hands	Legs	Lower legs[c]	Feet
<1[e]	0.182	0.0607	0.137	0.0617	0.053	0.206	0.082	0.0654
1<2[e]	0.165	0.0550	0.13	0.0585	0.0568	0.231	0.092	0.0627
2<3	0.142	0.0473	0.118	0.0531	0.053	0.232	0.093	0.0707
3<4	0.136	0.0453	0.144	0.0648	0.0607	0.268	0.107	0.0721
4<5	0.138	0.0460	0.14	0.0630	0.057	0.278	0.111	0.0729
5<6[f]	0.131	0.0437	0.131	0.0590	0.0471	0.271	0.108	0.069
6<7	0.131	0.0437	0.131	0.0590	0.0471	0.271	0.108	0.069
7<8[f]	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758
8<9[f]	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758
9<10	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758
10<11[f]	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703
11<12[f]	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703
12<13	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703
13<14	0.0997	0.0332	0.121	0.0545	0.0511	0.32	0.128	0.0802
14<15[f]	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693
15<16[f]	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693
16<17	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693
17<18	0.0758	0.0253	0.175	0.0788	0.0513	0.308	0.123	0.0728

Fraction of Total SA: Age-Weighted Body Part-Specific Average

<1 to <6	0.149	0.050	0.133	0.060	0.055	0.248	0.099	0.069
<7 to <18	0.097	0.032	0.133	0.060	0.053	0.307	0.123	0.072

Surface Area by Body Part (cm^2)[g]

	Head	Face	Arms	Forearms	Hands	Legs	Lower legs	Feet
<1 to <6	**977**	**326**	**874**	**393**	**358**	**1624**	**650**	**451**
<7 to <18	**1276**	**425**	**1749**	**787**	**700**	**4026**	**1610**	**949**

CHILDREN

Total Body SA (m^2, 50th %tile)[d]

Age (y)	Male Child	Female Child
<1[e]	0.603	0.579
1<2[e]	0.603	0.579
2<3	0.603	0.579
3<4	0.664	0.649
4<5	0.731	0.706
5<6[f]	0.793	0.779
6<7	0.866	0.843
7<8[f]	0.936	0.917
8<9[f]	1	1
9<10	1.07	1.06
10<11[f]	1.18	1.17
11<12[f]	1.23	1.3
12<13	1.34	1.4
13<14	1.47	1.48
14<15[f]	1.61	1.55
15<16[f]	1.7	1.57
16<17	1.76	1.6
17<18	1.8	1.63

			Total avg SA for male/female (m^2)
Total SA (<1to<6yr):	0.666	0.645	**0.656**
Total SA (<7to<18yr):	1.330	1.293	**1.312**

ADULT

Surface Area of Adults (cm^2 & 50th %tile)[a]

Body Part	Male	Female	Average
Total	19400	16900	**18150**
Face[b]	433	370	**402**
Forearms[c]	1310	1035	**1173**
Hands	990	817	**904**
Lower legs	2560	2180	**2370**
Feet	1310	1140	**1225**

[a] Taken from Exposure Factors Handbook (1997b) Table 6-8, p. 6-16 (mean values) for children, and Table 6-2 (male) and Table 6-3 (female), p. 6-13 for adults.

[b] Face SA assumed to be 1/3 of head SA (see Kissel et al. 1996b, Risk Analysis, 16: 115-125).

[c] Assumed forearm-to-arm ratio (0.45) and lowerleg-to-leg ratio (0.4) equivalent to that of an adult.

[d] Taken from Exposure Factors Handbook (1997b) Table 6-6 (male) and Table 6-7 (female) on p. 6-15.

[e] Due to lack of data for the indicated ages, assumed <1 & 1<2 yr olds had the same total body surface area (SA) as 2<3 yr olds.

[f] Due to lack of data for the indicated ages, assumed the body-part-specific fraction of total SA was equal to next oldest age that had data.

[g] Body-part weighted SA for children caculated by multiplying body-part-specific fraction of total SA by total avg. SA of male & female.

DRAFT

Following is a list of relevant notes about the SA calculations summarized in Table B.5:

- Adult SAs were taken from USEPA (1997d) Tables 6-2 (male) and 6-3 (female).
- Exposed SAs for the adult receptors were the 50th percentiles of the male and female (note that due to the lack of data, the female adult forearm SA was assumed to equal 45-percent of the arm SA).
- Children SAs were calculated using data from USEPA (1997d) Tables 6-6 (male total body SA), 6-7 (female total body SA), and 6-8 (male and female fraction of total SA).
- Due to the lack of data for certain ages, the fraction of total SA was assumed to be equal to the next oldest age group that had data, and the forearm-to-arm ratio (0.45) and lower leg-to-leg ratio (0.4) were assumed to be equivalent to those of an adult. These assumptions introduce some uncertainty into the calculation, but are used in the absence of age-specific data.

Clothing is expected to limit exposure to contaminants in soil. Therefore, surface areas that will be used in the dermal exposure calculations need to correlate with the exposed body parts. It is assumed that workers wear short-sleeved shirts, long pants, and shoes, therefore, the exposed body parts are the hands, forearms, and head (i.e., 3280 cm^2; refer to Table B.5).

It is assumed that adult and child residents wear short-sleeved shirts, shorts, and shoes or no shoes, therefore, the exposed body parts are the hands, forearms, head, lower legs, and feet (i.e., 5650 cm^2 for adults and 2830 cm^2 for children 0- to 6-years old; refer to Table B.5). While it is understood that this clothing scenario may not be appropriate year-round, some studies have suggested that exposure can occur under clothing (USEPA, 1992e). Therefore, this clothing scenario is not considered to be unduly conservative.

Soil Adherence Factors. Recent data from Kissel's laboratory (Kissel *et al.*, 1996a; Kissel *et al.*, 1996b; Kissel *et al.*,1998; and Holmes *et al.*, 1999) provide evidence to demonstrate that:

- Soil properties influence adherence;
- Soil adherence varies considerably across different parts of the body; and
- Soil adherence varies with activity.

Given these results, the USEPA (1997d) now recommends that activities which best represent all soils, body parts, and activities be used to derive soil adherence factors (AFs). Body part-weighted AFs can be calculated and used in estimating exposure via dermal contact with soil based on the assumed exposed body parts. Data on body part-specific AFs for specific activities are summarized in Table B.6 and were taken from

TABLE B.6
BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (AFs)
AND GEOMETRIC MEAN BODY PART-WEIGHTED AFs

Surface Area by Body Part (cm^2)	Face	Forearms	Hands	Lower legs	Feet	Total
<1 to <6 yr	326	393	358	650	451	2178
<7 to <18 yr	425	787	700	1610	949	4472
>18 yr	402	1173	904	2370	1225	6073

				Post-activity Loading (mg/cm^2)				
Activity	ID	Age	Gender	Hands	Arms	Legs	Faces	Feet
Groundskeepers No. 1	G1a	52	M	0.44	0.007	x [a]	0.004	0.024
	G1b	29	F	0.053	0.004	x	0.001	0.013
Groundskeepers No. 2	G2a	33	F	0.037	0.001	0.001	0.007	x
	G2b	34	M	0.20	0.006	0.001	0.018	x
	G2c	28	M	0.17	0.004	0.002	0.024	x
	G2d	37	F	0.056	0.001	0.001	0.007	x
	G2e	22	M	0.13	0.003	0.001	0.005	x
Groundskeepers No. 3	G3a	43	M	0.026	0.005	0.003	0.009	x
	G3b	40	F	0.006	0.001	0.0004	0.001	x
	G3c	45	F	0.058	0.002	x	0.003	0.004
	G3d	30	M	0.029	0.002	0.002	0.013	x
	G3e	43	M	0.034	0.002	0.001	0.005	x
	G3f	49	M	0.029	0.003	0.001	0.002	x
	G3g	62	M	0.086	0.004	0.001	0.010	x
Groundskeepers No. 4	G4a	38	F	0.067	0.011	0.0005	0.002	x
	G4b	30	M	0.030	0.021	0.001	0.006	x
	G4c	22	M	0.13	0.027	0.001	0.005	x
	G4d	34	F	0.050	0.005	0.002	0.002	x
	G4e	27	F	0.017	0.010	x	0.002	0.018
	G4f	29	M	0.034	0.012	0.0003	0.001	x
	G4g	35	M	0.053	0.022	0.001	0.003	x
Groundskeepers No. 5	G5a	44	M	0.052	0.032	0.001	0.006	x
	G5b	43	M	0.014	0.033	0.001	0.005	x
	G5c	40	F	0.016	0.018	0.001	0.001	x
	G5d	64	M	0.033	0.049	0.001	0.006	x
	G5e	45	F	0.042	0.030	0.001	0.002	x
	G5f	31	M	0.056	0.045	0.002	0.006	x
	G5g	49	M	0.033	0.024	0.001	0.004	x
	G5h	19	M	0.037	0.002	0.001	0.008	x
			Geometric Mean	0.046	0.007	0.001	0.004	0.012
			Residential Scenario Weighted AF (face,forearms,hands,lowerlegs)					1.1E-02
			Nonintrusive Worker Weighted AF (face,forearms,hands)					2.1E-02
Irrigation Installers	IR1	41	M	0.28	0.039	0.007	0.006	x
	IR2	35	M	0.28	0.014	0.004	0.006	x
	IR3	20	M	0.11	0.003	0.004	0.004	x
	IR4	23	M	0.13	0.008	0.003	0.008	x
	IR5	28	M	0.13	0.045	0.015	0.008	x
	IR6	23	M	0.30	0.062	0.007	0.007	x
			Geometric Mean	0.188	0.018	0.005	0.006	x
			Intrusive Worker Weighted AF (face, forearms,hands)					7.8E-02
Daycare Kids No. 1a	D1a1	6.5	M	0.25	0.027	0.067	x	0.21
	D1a2	4	M	0.088	0.044	0.015	x	0.087
	D1a3	2	M	0.21	0.043	0.030	x	0.024
	D1a4	1.75	M	0.081	0.027	0.023	x	0.11
	D1a5	1	M	0.11	0.029	0.041	x	0.031
	D1a6	1	F	0.042	0.008	0.027	x	0.17
Daycare Kids No. 1b	D1b1	6.5	M	0.094	0.018	0.026	x	0.21
	D1b2	4	M	0.089	0.024	0.019	x	0.12
	D1b3	2	M	0.51	0.037	0.023	x	0.13
	D1b4	1.75	M	0.10	0.035	0.027	x	0.11

TABLE B.6 (Continued)
BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (AFs)
AND GEOMETRIC MEAN BODY PART-WEIGHTED AFs

Activity	ID	Age	Gender	Post-activity Loading (mg/cm²)				
				Hands	Arms	Legs	Faces	Feet
Daycare Kids No. 3	D1b5	1	M	0.26	0.084	0.018	x	0.082
	D1b6	1	F	0.091	0.017	0.026	x	0.20
	D3a	4.5	M	0.031	0.015	0.017	x	0.015
	D3b	1.5	F	0.026	0.010	0.020	x	0.008
	D3c	1.3	M	0.040	0.011	0.040	x	0.013
	D3d	2	M	0.050	0.010	0.003	x	0.0005
			Geometric Mean	0.093	0.023	0.023	x	0.049
			Child Resident Weighted AF (forearms,hands,lowerlegs,feet)					4.0E-02
Landscape/Rockery	LR1	43	F	0.067	0.034	x	0.010	x
	LR2	36	M	0.16	0.060	x	0.007	x
	LR3	27	M	0.091	0.039	x	0.007	x
	LR4	43	M	0.028	0.010	x	0.002	x
			Geometric Mean	0.072	0.030	x	0.006	x
			Adult Resident Weighted AF (face,forearms,hands,lowerlegs)					4.1E-02
			Nonintrusive Worker Weighted AF (face,forearms,hands)					4.1E-02
Gardeners No. 1	GA1a	16	F	0.51	0.055	0.065	0.065	x
	GA1b	21	F	0.26	0.026	x	0.025	x
	GA1c	22	F	0.094	0.030	x	0.043	x
	GA1d	35	F	0.071	0.27	x	0.059	0.066
	GA1e	22	F	0.18	0.035	x	0.097	x
	GA1f	27	M	0.31	0.044	0.080	x	0.44
	GA1g	23	F	0.26	0.033	x	0.060	x
	GA1h	31	F	0.19	0.070	x	0.088	x
Gardeners No. 2	GA2a	43	F	0.15	0.048	0.053	0.093	x
	GA2b	32	M	0.17	0.059	x	x	0.26
	GA2c	34	M	0.26	0.071	x	0.058	x
	GA2d	32	F	0.083	0.018	0.013	0.024	x
	GA2e	33	F	2.1	0.41	x	0.056	x
	GA2f	52	F	0.12	0.049	0.028	0.031	x
	GA2g	26	F	0.043	0.017	0.013	0.047	x
			Geometric Mean	0.190	0.052	0.033	0.052	0.197
			Adult Resident Weighted AF (face,forearms,hands,lowerlegs)					6.8E-02
Construction Workers	CO1	26	M	0.38	0.13	0.066	0.033	x
	CO2	27	M	0.28	0.044	0.046	0.013	x
	CO3	24	M	0.23	0.13	0.056	0.045	x
	CO4	22	M	0.18	0.061	0.052	0.023	x
	CO5	22	M	0.44	0.13	0.13	0.035	x
	CO6	30	M	0.14	0.10	0.080	0.026	x
	CO7	24	M	0.16	0.13	x	0.058	x
	CO8	21	M	0.27	0.11	0.063	0.021	x
			Geometric Mean	0.24	0.10	0.07	0.03	x
			Intrusive Worker Weighted AF (face,forearms,hands)					1.4E-01
Utility Workers No. 1	U1a	45	M	0.15	0.052	x	0.095	x
	U1b	27	M	0.24	0.13	x	0.079	x
	U1c	24	M	0.56	0.18	x	0.084	x
	U1d	35	M	0.36	0.78	x	0.22	x
	U1e	24	M	0.44	0.31	x	0.082	x
Utility Workers No. 2	U2a	23	M	0.27	0.19	x	0.062	x
	U2b	28	M	0.91	0.83	x	0.20	x
	U2c	24	M	0.19	0.18	x	0.074	x
	U2d	34	M	0.11	0.30	x	0.11	x
	U2e	24	M	0.22	0.22	x	0.092	x
	U2f	36	M	0.39	0.43	x	0.12	x
			Geometric Mean	0.29	0.25	x	0.10	x
			Intrusive Worker Weighted AF (face,forearms,hands)					2.4E-01
Heavy Equipment Operators No. 1	E1a	54	M	0.12	0.053	x	0.064	x
	E1b	34	M	0.28	0.080	x	0.10	x
	E1c	51	M	0.15	0.091	x	0.15	x
	E1d	21	M	0.94	0.16	x	0.11	x

TABLE B.6 (Continued)
BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (AFs)
AND GEOMETRIC MEAN BODY PART-WEIGHTED AFs

Activity	ID	Age	Gender	Post-activity Loading (mg/cm²) Hands	Arms	Legs	Faces	Feet
Heavy Equipment	E2a	54	M	0.21	0.19	x	0.15	x
Operators No. 2	E2b	34	M	0.43	0.34	x	0.19	x
	E2c	51	M	0.23	0.22	x	0.50	x
	E2d	21	M	0.50	0.36	x	0.20	x
			Geometric Mean	0.29	0.15	x	0.15	x
				Intrusive Worker Weighted AF (face,forearms,hands)				2.0E-01
Children Playing	CPGPo1		M	1.4	0.026	1.3	0.013	x
(wet soil)	CPGPo2		F	0.29	0.005	0.18	0.010	x
	CPGPo3		M	0.13	0.009	0.037	0.012	x
	CPGPo4		M	0.93	0.069	0.67	0.009	x
	CPGPo5		M	0.036	0.008	0.004	0.005	x
	CPGPo6		F	0.56	0.011	0.010	0.002	x
	CPGPo7		F	0.68	0.015	0.13	0.006	x
	CPGPo8		M	0.16	0.006	0.072	0.004	x
	CPGPo9		F	4.7	0.101	0.78	0.006	x
	CPGPo10		M	5.0	0.064	0.001	0.002	x
	CPGPo11		M	0.27	0.003	0.0005	0.001	x
	CPGPo12		F	1.4	0.005	0.001	0.001	x
	CPGPo13		M	4.3	0.034	0.002	0.006	x
			Geometric Mean	0.656	0.015	0.026	0.004	x
				Child Resident Weighted AF (face,forearms,hands,lowerlegs)				1.5E-01
Children Playing	CPGPo14		M	0.19	0.015	0.056	0.002	x
(dry soil)	CPGPo15		M	0.14	0.010	0.022	0.004	x
	CPGPo16		F	0.021	0.002	0.020	0.002	x
	CPGPo17		M	0.15	0.018	0.017	0.002	x
	CPGPo18		F	0.10	0.095	0.34	0.022	x
			Geometric Mean	0.097	0.013	0.042	0.004	x
				Child Resident Weighted AF (face,forearms,hands,lowerlegs)				4.0E-02
Staged Activity:	APDGPo1a		M	0.13	0.003	0.001	0.003	x
Pipe Layers	APDGPo2a		M	0.24	0.036	0.26	0.006	x
(dry soil)	APDGPo3a		M	0.22	0.010	0.11	0.020	x
	APDGPo4a		F	0.16	0.009	0.046	0.003	x
	APDGPo5a		F	0.11	0.008	0.093	0.003	x
	APDGPo6a		F	0.17	0.008	0.30	0.003	x
	APDGPo1b		M	0.18	0.005	0.0003	0.001	x
	APDGPo2b		M	0.13	0.007	0.17	0.007	x
	APDGPo3b		M	0.13	0.11	0.11	0.004	x
	APDGPo4b		F	0.40	0.011	0.095	0.004	x
	APDGPo5b		F	0.12	0.015	0.11	0.008	x
	APDGPo6b		F	0.075	0.004	0.39	0.007	x
	APDGPo1c		M	0.55	0.005	0.001	0.002	x
	APDGPo2c		M	0.31	0.022	0.35	0.006	x
	APDGPo3c		M	0.18	0.088	0.25	0.004	x
	APDGPo4c		F	0.23	0.019	0.13	0.006	x
	APDGPo5c		F	0.17	0.010	0.10	0.012	x
	APDGPo6c		F	0.13	0.012	0.58	0.008	x
			Geometric Mean	0.179	0.012	0.066	0.005	x
				Intrusive Worker Weighted AF (face,forearms,hands)				7.2E-02

[a/] x = Not available because this body part was not given a post-activity washing on this individual.

Exposure Factors Handbook (USEPA, 1997d), Table 6-12 (p. 6-22), and from Holmes, *et. al* (1999). The raw data are available electronically at http://depts.washington.edu/jkspage/.

Given that soil adherence depends upon the body part, an overall body part-weighted AF is calculated for each activity. The assumed clothing scenario determines which body part-specific AFs are used in calculating the weighted geometric mean AFs. The weighted AFs are used with the relative absorption, exposure frequency and duration, exposed surface area, body weight, and averaging time to estimate the dermal absorbed dose.

The following general equation is used to calculate weighted AFs for particular activities.

$$Weighted\ AF = \frac{(AF_1)(SA_1) + (AF_2)(SA_2) + \ldots + (AF_i)(SA_i)}{SA_1 + SA_2 + \ldots + SA_i}$$

Where:

Weighted AF = Overall body part-specific weighted soil AF (mg/cm^2);

AF_i = AF for body part "i"; and

SA_i = SA for body part "i".

The results of the activity-specific weighted AF calculations are shown in Table B.7 and were calculated using the assumed exposed body parts described above. As noted in Table B.6, body part-specific AFs for both child and adult receptors were not always available for all body parts assumed to be exposed. Weighted adherence factors for receptors are calculated using only those body parts for which AFs are available because of the difficulty in trying to assign an AF for one body part to another body part. Therefore, the body part that may not have had AF data available is assumed, by default, to have the same amount of soil adhered as the weighted AF.

USEPA (1997d) suggests selecting an activity from the available AF data which best represents the exposure scenario of concern and using the corresponding weighted AF in the dermal exposure calculations. To make this selection, activities with available AFs can be categorized as those that nonintrusive workers, intrusive workers, adult residents, and child residents potentially would engage in (see Table B.7). Within each receptor category, activities are ranked in order from the activity with the lowest to highest weighted geometric mean AFs.

In some instances, the recommended default values for other contact rates (e.g., soil ingestion for a child) are based on high-end estimates of the mean. To maintain consistency with this approach, a high-end (i.e., reasonable but higher level of exposure) soil contact activity is selected and the body part-weighted geometric mean AF for that activity is used in the HRAs. It is not recommended that a high-end soil contact activity be used with a high-end weighted AF, as this use would not be consistent with the use of

TABLE B.7
BODY PART-WEIGHTED
SOIL ADHERENCE FACTORS

ACTIVITIES RELATED TO RECEPTOR TYPE	Age (yr)	Weighted AFs (mg/cm^2)[a/]
NONINTRUSIVE WORKER		
Groundskeepers	>18	**0.02**
Landscape/Rockery	>18	**0.04**
INTRUSIVE WORKER		
Staged Activity: Pipe Layers-Dry Soil	>15	**0.07**
Irrigation Installers	>18	**0.08**
Construction Workers	>18	**0.1**
Equip. Operators	>18	**0.2**
Utility Workers	>18	**0.2**
ADULT RESIDENT		
Groundskeepers	>18	**0.01**
Landscape/Rockery	>18	**0.04**
Gardeners	>16	**0.07**
CHILD RESIDENT		
Children Playing (dry soil)	8-12	**0.04**
Daycare Kids (played indoors and outdoors)	1-6.5	**0.04**
Children Playing (wet soil)	8-12	**0.15**

[a/] Weighted AFs based on geometric means.

an RME scenario. The justification for each receptor-specific weighted AF that may be used in the HRA is discussed in the following paragraphs.

Nonintrusive Worker. Data are available for two types of activities that nonintrusive workers may engage in: groundskeeping and landscaping (Table B.7). A body part-specific weighted AF of 0.04 mg/cm^2 is recommended for nonintrusive workers and is based on landscaping (the activity determined to represent a reasonable, high-end activity). The bases for this recommendation are: (1) although no single activity would represent the activities nonintrusive workers engage in, a comparison of the landscaper weighted AF with the groundskeeper weighted AF (Table B.7) suggests that landscaping represents a high-end soil contact activity; (2) common sense suggests that landscaping represents a high-end soil contact activity; and (3) selecting the central tendency weighted AF (i.e., geometric mean) of a high-end soil contact activity is consistent with an RME approach for contact rates.

Intrusive Worker. As shown in Table B.7, data are available for a wide variety of activities that an intrusive worker may engage in; pipe laying, installing irrigation systems, engaging in construction activities, operating heavy equipment, and laying/repairing utility lines. A body part-specific weighted AF of 0.2 mg/cm^2 is recommended for intrusive workers and is based on the weighted AF for utility workers (the activity determined to represent a reasonable high-end soil contact activity). The bases for this recommendation are: (1) although no single activity would be representative of activities an intrusive worker engages in, a comparison of the utility worker weighted AF with other intrusive-type activities (Table B.7) shows that the utility worker represents a high-end soil contact activity; (2) both common sense and data on weighted AFs support the assumption that utility worker activities represent high-end soil contact activities; and (3) selecting the weighted geometric mean AF of a high-end soil contact activity is consistent with an RME approach for contact rates.

Adult Resident. Data are available for three types of activities that adult residents may engage in; groundskeeping, landscaping, and gardening (Table B.7). A body part-specific weighted AF of 0.07 mg/cm^2 is recommended for adult residents and is based on gardening (the activity determined to represent a reasonable, high-end activity). The bases for this recommendation are: (1) although no single activity would represent the activities adult residents engage in, a comparison of the gardener weighted AF with the other residential- type of activities (Table B.7) shows that gardening represents a high-end soil contact activity; (2) common sense suggests that gardening represents a high-end soil contact activity; and (3) selecting the weighted geometric mean AF of a high-end soil contact activity is consistent with an RME approach for contact rates.

Child Resident. Available data on soil AFs for children is limited to children (1- to 6.5-years old) playing indoors and outdoors (3.5- to 4-hours/day) at a day care center (reviewed in USEPA, 1997d) and children (8- to 12-year old) playing for 20 minutes with an assortment of toys and implements in a preconstructed eight-by-eight ft soil bed (i.e., "staged" activity) containing dry or wet soil (see Kissel *et al.*, 1998). A weighted AF of 0.2 mg/cm^2 is recommended for the child resident and is based on children playing in wet soil (high-end soil contact activity).

Children playing at a day care center represents a CT (i.e., typical) activity given that: (1) the children played both indoors and outdoors; (2) the clothing worn was not controlled (i.e., some subjects wore long pants, long-sleeve shirts, and/or shoes); and (3) soil conditions were not controlled (e.g., differences in soil types and moisture content could result in higher AFs). The "staged" activity of children playing in wet soil for 20 minutes under controlled conditions (i.e., all subjects were clothed similarly, the duration of soil contact was controlled, and the soil properties were characterized) is a high-end soil contact activity because: (1) the children were in direct contact with soil for the full duration of the activity; and (2) the children played in wet soil, which is known to have higher AFs than dry soil, for the duration of the activity. Use of a weighted geometric mean AF of a high-end soil contact activity (i.e., children playing in wet soil) is consistent with an RME approach for contact rates.

While an AF value of 0.2 mg/cm^2 is at the lower end of the range of soil adherence factors reported in USEPA (1992e), which are based on Lepow *et al.* (1975) and Roels *et al.* (1980) studies, the Lepow and Roels studies were not designed to study soil adherence and only allowed calculation of soil adherence to hands. The AF of 0.2 mg/cm^2 recommended here is based on soil adherence studies for all of the relevant body parts (i.e., head, hands, forearms, lower-legs, and feet). Kissel *et al.* (1998) reports soil AFs for children's hands of 0.5-3 mg/cm^2 (median of 1 mg/cm^2) for relatively moist soil, which is comparable to the range of values previously reported for soil adherence to children's hands (0.5-1.5 mg/cm^2; USEPA, 1992e). The high soil contact activity body part-weighted AF of 0.2 mg/cm^2 for a child resident is technically defensible and falls within the range of values recommended by the USEPA (1992e).

Inhalation Rates. The inhalation chronic toxicity factors derived by USEPA (2000b) (i.e., inhalation unit risks (IURs) and reference concentrations (RfCs)) are expressed as air concentrations. USEPA (1994d, 1996b) recommends direct comparison of measured or modeled air concentrations to inhalation toxicity factors rather than using daily inhalation rates to convert to internal doses (i.e., mg/kg-day). Given that dosimetric adjustments (e.g., ventilation rate) based on adult ventilatory parameters have been used by the USEPA (2000b) in the derivation of select RfCs, a degree of uncertainty is introduced when applying these values to child receptors. However, as stated by USEPA (1994d, 2000b), "An inhalation reference concentration (RfC) is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer health effects during a lifetime." Therefore, direct comparison of measured or modeled air concentrations to inhalation toxicity factors without converting to internal doses is appropriate.

Fraction Contaminated. The fraction contaminated exposure parameter (e.g., fraction ingested) is defined as the fraction of medium (e.g., soil) contacted that is presumed to be contaminated. Fraction contaminated is dependent on the medium and exposure pathway being evaluated. The default value for fraction contaminated is one. This approach conservatively assumes that 100-percent of a receptor's daily exposure to the specified medium via a particular exposure pathway (e.g., soil ingestion) occurs on-site. The default value of one may be adjusted downward based on the availability of site-specific information.

Chemical-Specific Exposure Parameters. Chemical-specific parameters used in the HRAs should be based on appropriate site-specific data, USEPA recommendations, values reported in the scientific literature, or best scientific judgement. A reference for each value (e.g., dermal soil absorption factors, soil-to-air volatilization factors, skin permeability coefficients) should be included in a table listing chemical-specific properties used in the HRAs.

Fraction of Time Breathing Contaminated Air. Chronic inhalation toxicity factors developed by USEPA (2000b) assume continuous (i.e., daily, 24-hour exposure) long-term exposure. Therefore, it is necessary to adjust for the fraction of time breathing contaminated air for daily exposures less than 24-hours. For example, a value of 0.333 (unitless) should be used for workers breathing contaminated outdoor air if they work at the site 8 hours/day (i.e., 8 hours/24 hours = 0.333). In order to avoid overestimating residential exposure via inhalation of both outdoor and indoor air, values of 0.073 and 0.927 (unitless) should be used for the fraction of time adult and child residents breath outdoor and indoor air, respectively. The value of 0.073 is derived from the 50th percentile (105 minutes) for time spent outdoors per day at one's residence (i.e., 105 minutes/1440 minutes = 0.073; USEPA, 1997d) and is based on the National Human Activity Pattern Survey conducted by the USEPA (summarized in USEPA, 1997d). It should be assumed that the remaining fraction of time at one's residence (1 - 0.073 = 0.927) will be spent indoors.

Particulate Emission Factor. The PEF is defined as the factor that relates the concentration of the COPC in surface soil to the concentration of dust particles in air (USEPA, 1996b). Per USEPA (1996b), the PEF represents an annual emission rate based on wind erosion and should be used only for estimating chronic exposures. A PEF should be derived as described by USEPA (1996b) using site-specific parameters such as the fraction of vegetative cover, the mean annual windspeed, and a Q/C term that simulates the dispersion of contaminants in ambient air.

B.3 TOXICITY EVALUATION

The objective of the toxicity evaluation is to weigh available evidence regarding the potential for particular chemicals to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects. The toxicity evaluation of lead is discussed below, followed by a discussion for non-lead COPCs.

B.3.1 Lead

Although an elevated blood lead concentration is not an adverse health effect, the relationship between elevated blood lead levels and a range of adverse health effects is well established (ATSDR, 1993). The primary toxic effects of lead are observed in the central nervous system; however, virtually all parts of the body can be affected at high exposure levels. Lead can cause premature births, underweight babies, and/or decreased mental ability in infants or decreased intelligence quotient (IQ) scores and reduced growth in young children (ATSDR, 1993). In adults, exposure to lead at concentrations typically higher than those needed to elicit effects in children may decrease reaction time

and affect memory; cause weakness in the fingers, wrists, or ankles; increase blood pressure; and/or cause anemia (ATSDR, 1993). At very high levels of exposure, lead may damage the brain and/or the kidneys, induce abortion, or damage the male reproductive system (ATSDR, 1993). Specific health effects from lead exposure, the blood lead levels at which these effects were observed, and the literature in which the effects were reported are reproduced from the *Toxicological Profile for Lead* (ATSDR, 1993) and presented in Table B.8.

Although adverse health effects from lead exposure have been observed in people of all ages, exposure to lead is of particular concern for unborn or young children because children are more sensitive to its effects. This increased risk is due to a child's increased oral activity (e.g., hand-to-mouth behavior), increased tendency to absorb lead, and the increased susceptibility of the rapidly developing central nervous system of a fetus or child.

The Centers for Disease Control (CDC, 1991) has established blood lead concentration guidelines to help prevent childhood lead poisoning. CDC's recommended actions for children with elevated blood lead concentrations are summarized in Table B.9. The CDC's recommended actions include: 1) more frequent rescreening; 2) parental education on reducing lead exposure; 3) nutritional counseling; 4) environmental assessment and remediation; 5) medical evaluation; and 6) chelation therapy.

B.3.2 Non-Lead COPCs

In order to evaluate the risks/hazards associated with potential exposure to COPCs at a site, the types of health effects that may result from exposure to each COPC and the quantitative relationship between the amount of exposure and the extent of potential effects must be identified. Per USEPA (1989a), the toxicity assessment step includes the identification of appropriate exposure periods (e.g., chronic) and the determination of carcinogenic/noncarcinogenic toxicity factor. The objectives of the toxicity assessment are to weigh available toxicological evidence regarding the potential for particular chemicals to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects (i.e., toxicity factors).

The methodologies used to develop toxicity factors differ, depending on whether the COPC is a potential carcinogen (produces tumors) or a non-carcinogen (produces adverse health effects such as liver toxicity, kidney toxicity, neurotoxicity, etc.). The most recently available toxicity factors are used to calculate carcinogenic and noncarcinogenic risks/hazards based on the following general hierarchy of sources for toxicity factors:

- USEPA's (2000b) IRIS;
- USEPA's (1997e) HEAST; and
- Provisional values listed in regional publications of the USEPA (e.g., USEPA Region 9 [1999] Preliminary Remediation Goal [PRG] table or USEPA Region 3 [2000] Risk-Based Concentration [RBC] table)

TABLE B.8
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
<1 yr (occup)		Increase in death due to hypertension, nephritis, neoplasms	63-80	Cooper et al., 1985, 1988
NS (occup)		Increase in death due to cerebrovascular disease, nephritis, and/or nephrosis	NS	Fanning 1988; Malcolm and Barnett 1982; Michaels et al. 1991
<3 yr (occup)		No increase in deaths	34-58 (means)	Gerhardsson et al. 1986b
NS		Acute encephalopathy resulting in death in children	125-750	NAS 1972
2 wk - > 1 yr (occup)	Cardiovascular	Increased blood pressure	≥ 30- 120	deKort et al. 1987; Pollock and Ibels 1986; Marino et al. 1989; Weiss et al. 1986, 1988
>1 yr (occup)	Cardiovascular	No effect on blood pressure	40 (mean)	Parkinson et al. 1987
>1 yr (occup)	Cardiovascular	Ischemic electrocardiogram changes	51 (mean)	Kirkby and Gyntelberg 1985
NS (general population)	Cardiovascular	Increased blood pressure	44.9 (mean)	Khera et al. 1980
NS (general population)	Cardiovascular	Increased systolic pressure by 1-2 mmHg and increased diastolic pressure by 1.4 mmHg with every doubling in blood-lead level; effect most prominent in middle-aged white men	7-38	Coate and Fowles 1989; Harlan 1988; Harlan et al. 1988; Landis and Flegal 1988; Pirkle et al. 1985; Schwartz 1988
NS (general population)	Cardiovascular	No significant correlation between blood pressure and blood-lead levels	6-13 (median) or NS	Elwood et al. 1988; Grandjean et al. 1989; Neri et al. 1988; Staessen et al. 1990, 1991
NS (general population)	Cardiovascular	Degenerative changes in myocardium, electrocardiogram abnormalities in children	6-20	Silver and Rodriguez-Torres 1968

TABLE B.8 (Continued)
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
NS (acute) (occup)	Gastrointestinal	Colic (abdominal pain, constipation, cramps, nausea, vomiting, anorexia, weight loss)	40-200	Awad et al. 1986; Baker et al. 1979; Haenninen et al. 1979; Holness and Nethercott 1988; Kumar et al 1987; Marino et al. 1989; Matte et al. 1989; Muijser et al. 1987; Pagliuca et al. 1990; Pollock and Ibels 1986; Schneitzer et al. 1990
NS (acute) (general population)	Gastrointestinal	Colic in children	60- 100	U.S. EPA 1986; NAS 1972
NS (occup)	Hematological	Increased ALAS and/or decreased ALAD	87 or NS (correlated with blood-lead level)	Alessio et al. 1976; Meredith et al. 1978; Wada et al. 1973
NS (general population)	Hematological	Decreased ALAD	3-56 (adult) No threshold (children)	Chisholm et al. 1985; Lauwerys et al. 1978; Roels et al. 1976; Roels and Lauwerys 1987; Secchi et al. 1974
NS (occup)	Hematological	Increased urinary or blood ALA	< 40-50, 87 (mean) or NS	Lauwerys et al. 1974; Meredith et al. 1978; Pollock and Ibels 1986; Selander and Cramer 1970
NS (general population)	Hematological	Increased urinary ALA	> 35 (adult) 25-75 children	NAS 1972; Roels and Lauwerys 1987
NS (general population)	Hematological	Increased FEP	³ 25-35	Grandjean and Lintrup 1978; Roels et al. 1975
NS (general population)	Hematological	Increased EP	30-40 (males) 20-30 (females)	Roels and Lauwerys 1987; Roels et al. 1975, 1976, 1979; Stuick 1974
NS (general population	Hematological	Increased ZPP	≥ 15 (children)	Hammond et al. 1985; Piomelli et al. 1982; Rabinowitz et al. 1986; Roels and Lauwerys 1987; Roels et al. 1976
NS (general population)	Hematological	Increased urinary coproporphyrin	³ 35 (children) ³ 40 (adults)	U.S. EPA 1986
NS (occup)	Hematological	Decreased hemoglobin with or without basophilic stippling of erythrocytes	³ 40	Awad et al. 1986; Baker et al. 1979; Grandjean 1979; Lilis et al. 1978; Pagliuca et al. 1990; Tola et al. 1973; Wada et al. 1973
NS (general population)	Hematological	Decreased hemoglobin	³ 40 (children)	Adebonojo 1974; Betts et al. 1973; Pueschel et al. 1972; Rosen et al. 1974
NS (general population)	Hematological	Anemia (hematocrit of ~ 35%)	> 20 (children)	Schwartz et al. 1990

TABLE B.8 (Continued)
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
NS (occup)	Hematological	Decreased Py-5'-N	NS	Buc and Kaplan 1978; Paglia et al. 1975, 1977
NS (general population)	Hematological	Decreased Py-5l-N	7-80 (children)	Angle and Mcintire 1978; Angle et al. 1982
NS (acute) (general population)	Hepatic	Decreased mixed function oxidase activity	NS (children)	Alvares et al. 1975; Saenger et al. 1984
NS (chronic) (occup)	Renal	Chronic Nephropathy	40- > 100	Biagini et al. 1977; Cramer et al. 1974; Lilis et al. 1968; Maranelli and Apostoli 1987; Ong et al. 1987; Pollock and Ibeis 1986; Verschoor et al. 1987; Wedeen et al. 1979
1-30 yr (occup)	Renal	No effect on renal function	40-61	Buchet et al. 1980; Huang et al. 1988
NS (chronic) (general population)	Renal	Renal (impairment with gout or hypertension)	18-26 ug/dL	Batuman et al. 1981, 1983
NS (acute) (general population)	Renal	Aminoaciduria; Fancoi syndrome	> 80 (children)	Chisholm 1962; Pueschel et al. 1972
0.1-20 yr (chronic) (occup)	Other	Decreased thyroxin (T4)	³ 56	Tuppurainen et al. 1988
NS (chronic) (general population)	Other	No effect on thyroid function in children	2-77 (levels measured)	Siegel et al. 1989
NS (general population	Other	Negative correlation between blood lead and serum 1,25-dihydroxywitamin D in children	12-120	Mahaffey et al. 1982; Rosen et al. 1980
NS (chronic) (general population)	Other	No effect on vitamin D metabolism in children	5-24 (levels measured)	Koo et al. 1991
NS (chronic) (general population)	Other	Growth retardation in children	³ 30-60; Tooth lead > 18.7 µg/g	Angle and Kuntzelman 1989; Lauwers et al. 1986; Lyngbye et al. 1987
NS (chronic) (general population)	Other	No association between blood-lead levels and growth in children	10-47 (levels measured)	Greene and Ernhart 1991; Sachs and Moel 1989
18 yr (occup)	Immunological	Depression of cellular immune function, but no effect on humoral immune function	21 -90	Alomran and Shleamoon 1988; Ewers et al. 1982
NS (acute)	Neurological	Encephalopathy (adults)	50- > 300	Kehoe 1961; Kumar et al. 1987; Smith et al. 1938

TABLE B.8 (Continued)
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
NS (acute and chronic) (occup)	Neurological	Neurological signs and symptoms in adults including malaise, forgetfulness, irritability, lethargy, headache, fatigue, impotence, decreased libido, dizziness, weakness, paresthesia	40-80	Awad et al. 1986; Baker et al. 1979; Campara et al. 1984; Haenninen et al. 1979; Holness and Nethercott 1988; Marino et al. 1989; Matte et se. 1989; Pagliuca et al. 1990; Parkinson et al. 1986; Pasternak et al. 1989; Pollock and Ibels 1986; Schneitzer et
NS (occup)	Neurological	Neurobehavioral function in adults; disturbances in oculomotor function, reaction time, visual motor performance, hand dexterity, IQ test and cognitive performance, nervousness, mood, coping ability, memory	40-80	Arnvig et al. 1980; Baker et al. 1983; Baloh et al. 1979; Campara et al. 1 984; Glickman et al. 1984; Haenninen et al. 1978; Hogstedt et al. 1983; Mantere et al. 1982; Spivey et al. 1980; Stollery et al. 1989; Valciukas et al. 1978; Williamson and Teo 198
NS (occup)	Neurological	No effect on neurobehavioral function in adults	40-60 (levels measured)	Milbum et al. 1976; Ryan et al. 1987
NS (occup) /E2/bk	Neurological	Peripheral nerve function in adults; decreased nerve conduction velocity	30- [3] 70	Araki et al.1980; MuiJser et al. 1987; Rosen et al. 1983; Seppalainen et al. 1983; Triebig et al. 1984
NS (occup)	Neurological	No effect on peripheral nerve function	B 60-80 (levels measured)	Spivey et al. 1980
NS(general population)	Neurological	Neurological signs and symptoms in children and encephalopathy	60-450 (effects other than encephalopathy); > 80-800 (encephalopathy)	Bradley and Baumpartner 1958; Bradley et al. 1956; Chisolm 1962, 1 965; Chisolm and Harrison 1956; Gant 1938; Rummo et al. 1979; Smith et al. 1983
NS (general population)	Neurological	Neurobehavioral function in children: lower IQS and other neuropsychologic deficits	40-200	dela Burde and Choate 1972, 1975; Emhartetal. 1981; Kotok 1972; Kotok et al. 1977; Rummo et al. 1979

TABLE B.8 (Continued)
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
NS (general population)	Neurological	Neurobehavioral function in children: slightly decreased performance on IQ tests and other measures of neuropsychological function	Tooth lead: 6 - > 30 µg/g Blood lead: 6-60	Bellinger and Needleman 1983; Bergomi et al. 1989; Fulton et al. 1987; Hansen etal. 1989; Hawketal. 1986; Needleman et al. 1979, 1985, 1990; Schroeder et al. 1985; Schroeder and Hawk 1987; Silva et al. 1988; Wang et al. 1989
NS (general population)	Neurological	No correlation between blood-lead levels and permanent effects on neurobehavioral development in children	10-15	Cooney et al. 1989; Harvey et al. 1984, 1988; Lansdown et al. 1986; McBride et al. 1982; Ernhart and Greene, 1990; Dietrich et al. 1987a; Bellinger et al. 1989a; McMichael et al. 1986; Pocock et al. 1989; Smith et al. 1983; Winneke etal. 1984
NS (general population)	Neurological	Decrease in hearing acuity in children	4-60	Schwartz and Otto 1987
NS (general population)	Neurological	Alterations in peripheral nerve function in children	20-30	Erenberg et al. 1974; Landrigan et al. 1976; Schwartz et al. 1988; Seto and Freeman 1964
prenatal (general population)	Developmental	Decreased growth rate	7.7	Shukla et al. 1989
prenatal (general population)	Developmental	Reduced birth weight and/or reduced gestational age, and/or increased incidence of stillbirth and neonatal death	12-17	Bornschein et al. 1989; McMichael et al. 1986; Moore et al. 1982; Ward et al. 1987; Wibberley et al. 1977
NS(general population)	Developmental	No association between blood-lead levels and birth weight, gestational age, or other neonatal size measures	3-55	Greene and Ernhart 1991; Factor-Litvak et al. 1991
NS (general population)	Developmental	Impaired mental development in children	10-15	Baghurst et al. 1987; Bellinger et al. 1984, 1985a, 1985b, 1986a, 1986b, 1987a, 1987b; Bornschein et al. 1989; Dietrich et al. 1986, 1987a, 1987b; Ernhar tetal. 1985, 1986, 1987; McMichael et al. 1988; Rothenberg et al. 1989; Wigg et al. 1988; Winneke et
NS(general population)	Developmental	Inverse correlation between blood-lead levels and ALA and ALAD activity	10-33 (mean)	Haas et al. 1972; Kuhnert et al. 1977; Lauwerys et al. 1978

TABLE B.8 (Continued)
HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO LEAD

Duration of Exposure	System	Effect	Blood Lead Levels at which Effect is Observed (µg/dL)	References [a/]
NS(general population	Reproductive	Increased incidence of miscarriages and stillbirths in exposed women	[3] 10 or NS	Baghurst et al. 1987; Hu et al. 1991; McMichael et al. 1986; Nordstrom et al. 1979; Wibberley et al. 1977
NS(general population)	Reproductive	No association between blood-lead levels and the incidence of spontaneous abortion in exposed women	2	Murphy et al. 1990
NS (occup)	Reproductive	Adverse effects on testes	40-50	Assennato et al. 1987; Braunstein et se. 1978; Chowdhury et al. 1986; Cullen et al. 1984; Lancranjan et al. 1975; Rodamilans et al. 1988; Wildt et al. 1983

[a/] References cited as listed in ATSDR (1993)

ALA = õ-aminolevulinic acid; ALAD = õ-aminolevulinic acid dehydratase; ALAS - õ-aminolevulinic acid snythase; EP = erythocyte protoporphyrins; FEP = free erythrocyte protoporphyrins; IQ = intelligence quotient; mmhg = millimeters of mercury; NS = not spec

/E2/bb

TABLE B.9
INTERPRETATION OF BLOOD LEAD CONCENTRATIONS AND RECOMMENDED ACTIONS BY CDC [a/]

Class	Blood Lead Concentration (µg/dL)	Recommended Action
I	≤ 9	A child in Class I is not considered to be lead-poisoned.
IIA	10-14	Many children (or a large proportion of children) with blood-lead levels in this range should trigger community-wide childhood lead poisoning prevention activities. Children in this range may need to be rescreened more frequently.
IIB	15-19	A child in Class IIB should receive nutritional and educational interventions and more frequent screening. If the blood lead level persists in this range, environmental investigation and intervention should be done.
III	20-44	A child in Class III should receive environmental evaluation and remediation and a medical examination. Such a child may need pharmacologic treatment of lead poisoning.
IV	45-69	A child in Class IV will need both medical and environmental interventions, including chelation therapy.
V	≤ 70	A child with Class V lead poisoning is a medical emergency. Medical and environmental management must begin immediately.

[a/] CDC, 1991.

Oral toxicity values reflect administered-dose values, which represent concentrations that will be protective if ingestion occurs. Inhalation toxicity values are representative air concentrations that will be protective following inhalation (24 hours/day). The dermal route of exposure, however, evaluates the toxicity of concentrations of chemicals in the blood (absorbed dose). Therefore, the absorbed-dose concentrations identified for dermal exposure must be compared to toxicity values adjusted for gastrointestinal absorption. Toxicity values adjusted for gastrointestinal absorption are derived by applying oral absorption factors to administered-dose toxicity values. Adjustment of an oral slope factor (SF) or reference dose (RfD) are performed when the following conditions are met:

- The critical study upon which the toxicity value is based employed an administered dose (e.g., delivery in diet or by gavage) in its study design; and
- A scientifically defensible data base exists and demonstrates that the gastrointestinal absorption of the chemical in question, from a media (e.g., water, feed) similar to the one employed in the critical study, is less than 100-percent.

Oral absorption factors are obtained from the literature (citations should be provided; e.g., values used by USEPA Region 9 [1999]), if possible. In the absence of oral absorption factors in the literature, default values provided by USEPA Region 4 (1996) may be used (e.g., 50-percent for semi-volatile organic compounds [SVOCs] and 20-percent for inorganics).

B.4 RISK CHARACTERIZATION

The purposes of the risk characterization step are to review the results from the exposure and toxicity evaluations and quantitatively estimate the potential for cancer (i.e., risk) and non-cancer (i.e., hazard) effects.

B.4.1 Lead

The OSWER guidance (USEPA, 1994a) that calls for the establishment of cleanup goals to limit the childhood risk of exceeding a 10-µg/dL blood-lead level to 5-percent is based on the CDC (1991) conclusion that children with blood lead concentrations of ≤9 µg/dL are not considered to be lead-poisoned. Although there is not a specific reference toxicity value for lead exposure (particularly for estimated fetal blood lead concentrations), the ranges of childhood blood lead concentrations and the corresponding CDC recommended actions listed in Table B.9 provide a basis for determining the potential seriousness of estimated child or fetal blood concentrations.

B.4.2 Non-Lead COPCs

To characterize potential non-carcinogenic effects, comparisons are made between estimated exposure levels of non-lead COPCs and their toxicity values. To characterize potential carcinogenic effects, the incremental probability of an individual developing cancer over a lifetime is calculated from estimated exposure levels and chemical-specific dose/response information (i.e., carcinogenic toxicity factors). Cancer risk (for carcinogens) and hazard quotient (HQ; for non-carcinogens) estimates are calculated as described below for each non-lead COPC having available toxicity factors.

B.4.2.1 Non-carcinogenic Effects

The potential for non-carcinogenic effects is evaluated by comparing the estimated exposure level over a specified time period with non-carcinogenic toxicity factors derived for a similar exposure period. This ratio is termed the HQ, or in other words, the HQ is the ratio of the exposure level to the non-cancer toxicity factor:

Oral HQ = exposure intake (administered dose)/oral RfD (administered dose);

Inhalation HQ = modeled air concentration X exposure factors/RfC, as shown in the following equation:

$$\frac{(C_{(air\text{-}Particluate\ /\ VOC)})(EF)(ED)(ET)}{(AT)(365 days/year)} \ / \ \text{RfC},$$

where:

$C_{(air\text{-}Particulate/VOC)}$ = C_{soil} /PEF or VF , where

C_{soil} = COPC concentration in soil (i.e., EPC);

PEF = Particulate emission factor; and

VF = Volatilization factor;

EF = Exposure frequency (days/year);

ED = Exposure duration (years);

ET = Fraction of EF time breathing air at the site;

AT = Noncancer averaging time (years); and

Dermal HQ = intake (absorbed dose)/oral RfD (absorbed dose).

The HQ approach assumes that there is a level of exposure (i.e., RfD or RfC) below which it is unlikely that even sensitive populations would experience adverse health effects. If the exposure level exceeds the threshold (i.e., if HQ exceeds unity), there may be concern for potential noncancer effects. Per USEPA (1989a), the greater the HQ above unity, the greater the level of potential concern.

B.4.2.2 Carcinogenic Effects

Carcinogenic risk is expressed as an increased probability of developing cancer as a result of lifetime exposure. For a given COPC and route of exposure, carcinogenic risk is calculated as follows:

Oral risk = exposure intake (administered dose) x oral slope factor (administered dose);

Inhalation risk = (modeled air concentration) x (exposure parameters) x (IUR); as shown in the following equation:

$$\frac{(C_{(air\text{-}Particluate\ /\ VOC)})(EF)(ED)(ET)}{(AT)(365 days/year)} * IUR$$

where:

$C_{(air\text{-}Particulate/VOC)}$ = C_{soil} /PEF or VF , where

C_{soil} = COPC concentration in soil (i.e., EPC);

PEF = Particulate emission factor; and

VF = Volatilization factor; or

EF = Exposure frequency (days/year);

ED = Exposure duration (years);

ET = Fraction of EF time breathing air at the site;

AT = Cancer averaging time (years); and

Dermal risk = intake (absorbed dose) x oral SF (absorbed dose).

B.4.2.3 Cumulative Effects

To assess the overall potential for noncarcinogenic effects posed by more than one exposure route and more than one chemical (i.e., cumulative hazards from exposure to multiple COPCs via multiple exposure routes), a hazard index (HI) approach has been developed by the USEPA (1989a). This approach assumes that simultaneous subthreshold exposures to several chemicals via multiple exposure routes could result in an adverse health effect, while acting on the same target organ. The HI is calculated as follows:

$$HI = HQ_1 + HQ_2 + ... + HQi$$

where:

HQ*i* = the hazard quotient for the *i*th toxicant summed across all relevant exposure routes.

According to USEPA (1989a) guidance for estimating risk from exposures to noncarcinogens, HI values can be derived based on similar target organ effects (if necessary). For those receptors with HIs exceeding one (assuming all COPCs act on the same target organ), cumulative HIs by target organ are calculated per USEPA (1989a) guidance. For those COPCs that do not have known target organ effects, it is assumed these chemicals could effect any target organ.

Calculation of an HI in excess of one indicates the potential for adverse health effects. Indices greater than one will be generated any time estimated exposure for any of the COPCs exceeds its RfD or RfC. If there are two or more COPCs, it is possible to generate a HI greater than one, even if none of the estimated exposure levels for individual COPCs exceed their respective RfDs or RfCs.

For simultaneous exposure to several carcinogens via multiple exposure routes, cumulative risk is calculated using the following equation:

$$Risk_T = Risk_1 + Risk_2 + ... + Risk_i$$

where:

$Risk_T$ = the total cancer risk, expressed as a unitless probability; and

$Risk_i$ = the risk estimate for the *i*th substance summed across all relevant exposure routes.

B.5 UNCERTAINTY ANALYSIS

All risk assessments involve the use of assumptions, professional judgments, and imperfect data to varying degrees, which results in uncertainty in the final estimates of hazard and risk. Risk assessment in general is highly conservative and often is based on conservative assumptions and scenarios. Uncertainty can be introduced into a health risk assessment at every step of the process. Uncertainties are present in a risk assessment because it requires the integration of the following:

- The release of pollutants into the environment;
- The fate and transport of pollutants, in a variety of different and variable environments, by processes that are often poorly understood or too complex to quantify accurately;
- The potential for adverse health effects in humans based on extrapolations from animal studies; and
- The probability of adverse effects in a human population that is highly variable with respect to genetics, age, activity level, and lifestyle.

There are several categories of uncertainty associated with risk assessment. One is the initial selection of chemicals for analyses and, therefore, which chemicals are used to characterize risk from exposure. A second category is the selection of exposure scenarios that are conservative (i.e., protective of human health) and yet which are probable. Additional uncertainties are inherent in the exposure assessment for individual substances and individual exposures. These uncertainties are driven by the degree of reliability of the chemical monitoring data, the models used to estimate EPCs in the absence of monitoring data, and the population intake parameters (e.g., exposure factors). A third category is the availability of toxicity information for the COPCs at the site to address all potential routes of exposure. Finally, additional uncertainties are incorporated into the risk assessment when exposures to several substances are summed.

The following subsections describe the likelihood that the approaches incorporated into the human health assessment may result in an over- or underestimate of the actual risks associated with exposure to COPCs. The relative impact these uncertainties may have on the human health risk assessment results can be summarized in tabular format (e.g., Table B.10).

B.5.1 Chemicals of Potential Concern

The sampling data collected at any site are inevitably a limited subset of the nearly unlimited quantity of data that potentially could be collected, which may result in over- or underestimation of risk. Conversely, given that the objective of the sampling and analysis process is to define the nature and extent of contamination, samples may not be collected randomly and may be biased toward overestimation of chemical concentrations at the site.

Uncertainty also is inherent in the selection of COPCs. Uncertainty in contaminant identification should be low because the sampling protocol should target appropriate analytes based on historical site information. Reasonable certainty also should be

TABLE B.10
UNCERTAINTIES ASSOCIATED WITH THE HUMAN HEALTH EVALUATION

Uncertainty Factor	Effect of Uncertainty [a/]	Comment
Data Collection and Evaluation		
Sampling and analysis methods	++ or --	Errors associated with sample collection and analysis, number and location of samples, and heterogeneity of samples impact results.
Chemicals that were not detected	+ or -	Risk may be under or overestimated if a chemical that is present was not detected because of potential antagonistic or synergistic effects.
Comparison to background concentrations	+ or -	Highly dependent on the number and location of samples and the statistical methods used to calculate site exposure-point and background concentrations. The smaller the sample set, the lower the confidence in the statistical results.
Exposure Assessment		
Soil exposure intervals	++ or --	Assumed exposure to the nonintrusive worker could occur throughout the 0- to 0.5-foot bgs soil depth interval as a result of normal work activities. Assumed a future intrusive industrial worker and future hypothetical resident could be exposed to soils from 0 to 12 feet bgs as a result of mechanical mixing (i.e., excavation) or fate and transport processes.
Exposure area	++	Assumued site boundaries are equivalent to exposure area. Generally, firing range sites are small and actual exposure area likely is larger.
Exposure pathways	++ or --	Assumed exposure via the incidental ingestion, dermal contact with, and inhalation of contaminants in soil.
Exposure parameters	++ or --	Models highly dependent on the input parameters (see text for further discussion of input parameters)
Exposure-Point Concentrations and Intake Values		
Exposure-Point Concentrations	+ or -	Used parametric and nonparametric statistical methods to estimate exposure-point concentrations. These values may be under or overestimated depending on how representative the site data is to site conditions.
RME Values	++	Used reasonable maximum exposure (RME) central tendency to provide a conservative estimate of high-end risk at the sites. Central tendancy (CT) values only used for comparison (i.e., not decision-making) purposes.
Toxicity Assessment		
Use of oral toxicity factors for dermal toxicity assessment	+ or -	Oral toxicity values adjusted for gastrointestinal absorption may over- or underestimate depending on actual bioavailability of contaminants at the site.

[a/] Potential magnitude of overestimation (plus symbols) or underestimation (minus symbols) of risk: "+ or –" = low; "++ or - -" = moderate; and "+++ or - - -" = high.

assumed because of sample data validation and quality assurance/quality control procedures applied to sample analysis and data evaluation.

B.5.2 Exposure Evaluation

Factors that can contribute to uncertainty in the exposure evaluation include identification of exposure pathways; assumptions for scenario development, intake parameters, and exposure pathways; and derivation of EPCs.

The identification of potential exposure pathways and receptors should be based on site-specific current and reasonable potential future land use. Site-specific receptors should be identified to the extent possible, and exposure parameters tailored to these receptors to minimize uncertainty in the postulated scenarios and exposure assessments.

Values for exposure parameters (e.g., inhalation rates and exposure frequencies) used in calculations for intakes may result in underestimating or overestimating intakes, depending on the accuracy of the assumptions relative to actual site conditions and uses.

B.5.3 Toxicity Evaluation

Uncertainty is inherent in the toxicity values used in characterizing hazards. Such uncertainty is chemical-specific and is incorporated into the toxicity value during its development. For example, an uncertainty factor may be applied for interspecies and intrahuman variability, for extrapolation from subchronic to chronic exposures, or for epidemiological data limitations.

Toxicity values are not available for all COPCs and exposure pathways, thereby precluding their inclusion in the quantitative risk estimates. The resulting risk estimates do not include the chemical-specific risks for these chemicals and exposure pathways, and, therefore, may underestimate risk.

Toxicity information specific to dermal exposure is not available for many chemicals. The use of gastrointestinal absorption factors poses uncertainty when used to convert oral toxicity values to criteria that can be used in the dermal exposure assessment. In the absence of chemical-specific dermal or gastrointestinal absorption values, default surrogate values may be assigned, which may over- or underestimate risk.

B.5.4 Risk Characterization

Uncertainties in the risk characterization are compounded under the assumption of dose additivity for multiple substance exposures. This assumption ignores possible synergisms and antagonisms among chemicals. The assumption that all the toxic effects are additive could result in the underestimation of risk because concurrent exposure to several contaminants might have synergistic toxic effects (e.g., exposure to two metals concurrently might induce a greater toxic effect than indicated by simply adding the toxic effects from each metal). Conversely, summing risks for chemicals having various weight-of-evidence classifications as well as toxic effects to different target organs and ignoring possible antagonistic effects of some chemicals may overestimate risks.

Assumptions built into the HRA will tend to overestimate rather than underestimate potential risks, including conservative assumptions for the exposure scenarios. For example, it was conservatively assumed that a hypothetical industrial worker would be present at the site 8 hrs/day for 219 to 250 days per year. Given the current and expected future land use (i.e., open space), this assumption likely significantly overestimates risk.

B.5.5 Uncertainties Associated with Adult Blood-Lead Modeling

There are several categories of uncertainty associated with adult blood-lead exposure modeling. One category is the selection of exposure parameters that are protective of human health and that are probable. Uncertainties are driven by the degree of reliability of the chemical sampling data, the models used to estimate EPCs, and the population intake parameters (e.g., exposure factors). Another category is the availability of and uncertainty associated with toxicity information for the COPCs at a site.

A summary of the uncertainties associated with the human health risk estimates determined using the TRW's Adult Blood Lead Model (USEPA, 1996c), along with the impact of these uncertainties on the results can be provided in tabular format (e.g., Table B.11).

A brief discussion of the uncertainties associated with the TRW Adult Lead Model follows.

B.5.5.1 Individual Blood Lead Geometric Standard Deviation and Baseline Blood Lead Concentrations

Ideally, GSD_i and $PbB_{adult,0}$ should be based on actual measurements in the population of concern and an appropriate control population at the site, respectively. However, in the absence of site-specific measurements, GSD_i and $PbB_{adult,0}$ can be extrapolated from estimates for other populations. Uncertainties associated with extrapolating from surrogate populations include, but are not limited to, variability in exposure (level and pathways), biokinetics, socioeconomic and ethnic characteristics, degree of urbanization, and geographical locations. In order to reduce uncertainties, site-specific demographic information (e.g., US Census Bureau data) and values reported by TRW (USEPA, 1996c) can be used to estimate GSD_i and $PbB_{adult,0}$. Uncertainties associated with determining population demographics include determining the appropriate exposed and control populations and using Census Bureau data to represent current and future demographics. The TRW (USEPA, 1996c) reported default GSD_i and $PbB_{adult,0}$ values for only three adult female demographic categories (non-Hispanic whites, non-Hispanic blacks, and American Mexicans), which may lead to slight over- or underestimation of risk.

TABLE B.11
EXAMPLE OF UNCERTAINTIES ASSOCIATED WITH THE ADULT BLOOD-LEAD MODELING

Uncertainty Factor	Effect of Uncertainty [a/]	Comment
Selection of COPCs		
Sampling and analysis methods	++ or --	Errors associated with sample collection and analysis, number and location of samples, and heterogeneity of samples impact results.
Comparison to background concentrations	+ or --	Highly dependent on the number and location of samples and the statistical methods used to calculate site exposure-point and background concentrations. The smaller the sample set, the lower the confidence in the statistical results.
Exposure Evaluation		
Soil exposure intervals	++ or --	Exposure to the nonintrusive worker could occur throughout the 0- to 2.5-feet bgs soil depth interval as a result of mechanical mixing (i.e., tilling with a tractor and disc) or fate and transport processes.
Exposure area	++	Site boundary often assumed to be representative of current/future exposure area. Actual exposure area may vary.
Exposure pathways	+ or --	Per USEPA (1996c), assumed primary exposure to adult nonresidential receptors occurs primarily through incidental ingestion of soil. Other exposure routes at site (e.g., dermal contact, inhalation of site dust) may contribute to risk
Use of TRW Adult Lead Model (USEPA, 1996c)	+ or -	TRW recognizes other adult lead models are available for supporting more detailed prediction of lead uptake and exposure. However, TRW believes recommended approach useful for assessing most sites where places of employment are (or will be) situated on lead contaminated soils and will promote consistency.
Exposure parameters used in model	++ or --	Model highly dependent on the input parameters (see text for further discussion of input parameters)
Sensitive receptor (i.e., fetus of adult nonintrusive worker) protective of other receptors	+++	Because the fetuses in pregnant adult workers are considered to be a sensitive subpopulation, estimating risk for this receptor likely overestimates risk for other adult receptors because: 1) the health endpoint is less sensitive for nonpregnant adults (slight increase in blood pressure at 10-30 µg/dL blood lead [ATSDR, 1993]) than children (developmental effects in children with ≥ 10 µg/dL blood [ATSDR, 1993]); and 2) exposure in adults is less than expected in fetuses.
Toxicity Evaluation		
Threshold for adverse effect from lead exposure	++ or -	Adverse health effects associated with lead exposure in children are assumed same as expected for fetuses. Toxicological data base used to derive threshold concentration is a source of uncertainties, including, gender, age, differences in uptake, metabolism, organ distribution, target site susceptibility, and human population variability with respect to diet, environment, activity patterns, and cultural factors.

[a/] Potential magnitude of overestimation (plus symbols) or underestimation (minus symbols) of risk: "+ or –" = low; "++ or - -" = moderate; and "+++ or - - -" = high.

B.5.5.2 Fetal/Maternal Blood Lead Concentration Ratio

Although there are consistent trends in the ratio of fetal blood to maternal blood lead, TRW (USEPA, 1996c) acknowledges the uncertainties due to inter-individual physiological changes associated with pregnancy. In addition, nutritional status may affect blood lead levels in women of child-bearing age, resulting in over- or underestimation of risk to the fetus. For example, TRW (USEPA, 1996c) reviewed

literature results which showed that blood lead concentrations in the pregnant women may decrease during the later stages of pregnancy.

B.5.5.3 Biokinetic Slope Factor

There are several uncertainties associated with applying a default value for BKSF. For example, the TRW default value is derived by extrapolating data for adult men to women of child-bearing age (USEPA, 1996c). Physiological changes associated with pregnancy may result in the default BKSF being an over- or underestimate. In addition, the assumption of linearity for the relationship between lead intake and blood lead concentration introduces uncertainties. However, because the default BKSF value derived from population survey data is consistent with estimates from experimental studies, the assumption of linearity seems to be appropriate.

B.5.5.4 Soil Lead Absorption Factor

As discussed by the TRW (USEPA, 1996c), there are three major sources of variability that contribute to the uncertainties associated with AF_s: variability in food intake, lead intake, and lead form and particle size. For example, the bioavailability of ingested soluble lead has been shown to vary from less than 10 percent when ingested with a meal to 80 percent when ingested after fasting (reviewed in USEPA, 1996c). However, $AF_{soluble}$ estimates should account, in part, for meal patterns within the general population. In addition, site-specific *in-vitro* bioavailability results used in conjunction with site-specific lead speciation data reduce the uncertainties associated with $RBF_{soil/soluble}$.

B.5.5.5 Daily Soil Ingestion Rate

USEPA (1996c) recommends using a value of 0.05 g/day to describe all sources of ingested soil for occupational exposures. This is consistent with the recommendations of the Superfund program, where 0.05 g/day is used to address all occupational soil intake by the adult, whether directly from soil or indirectly through contact with dust (USEPA, 1993c). Uncertainties associated with the use of this default value include site-specific soil contact intensity and seasonal variations. In addition, USEPA (1997d) points out that only three studies have attempted to estimate adult soil ingestion. The first study (Hawley, 1985) derived estimates based on assumptions about soil/dust levels on hands and mouthing behavior, and did not collect supporting measurements. Given the lack of supporting measurements, USEPA (1997d) considers the Hawley (1985) estimates conjectural. Krablin (1989) used arsenic levels in urine and assumptions on mouthing behavior and activity patterns to estimate adult soil ingestion rates. Per USEPA (1997d), the confidence in the Krablin (1989) estimates is low because the study protocols are not well described and the estimates have not been formally published. The adult soil ingestion study that is probably the most reliable was a 2-week tracer study on six adults (Calabrese *et al.*, 1990). This study has two significant uncertainties: 1) representativeness given the small sample size (n = 6); and 2) representativeness of long-term behavior given the short duration of the study (2 weeks). Based on a review of these studies, USEPA (1997d) concluded that 0.05 g/day represents a reasonable estimate of

adult soil ingestion, and considering the uncertainties in the CT estimate, a recommendation for an upper-percentile value would be inappropriate.

B.5.5.6 Exposure Frequency

The default value of 219 days/yr recommended by USEPA (1996c) represents the CT occupational estimate recommended by USEPA (1993c) Superfund guidance. However, USEPA (1996c) recognizes the uncertainty associated with this estimate and acknowledges that exposure scenarios where EFs are substantially less than 219 days/yr are frequently encountered.

B.5.6 Uncertainties Associated with the IEUBK Model

Per USEPA (1994c), the IEUBK model is used to estimate geometric mean blood lead levels in future residential children exposed to lead site soils. A number of key uncertainties associated with the application of this model are discussed in this section.

B.5.6.1 Multiple Environmental Sources of Lead

Ideally, site-specific data on the lead concentrations in air, water, soil, household dusts, and average daily intake of lead from diet and from direct ingestion of paint chips should be used in the IEUBK model (USEPA, 1994c). In the absence of site-specific data, USEPA (1994c) recommends use of default input parameters. However, use of default input parameters as source concentrations of lead may lead to an over- or underestimate of risk from lead exposure.

B.5.6.2 IEUBK Model Validation

The IEUBK model (USEPA, 1994c) has incorporated a detailed biokinetic modeling component. It is a compartmental model and assumes that all of the lead in a child's body can be attributed to one of seven compartments (i.e., extra-cellular fluids, red blood cells, kidney, liver, other soft tissue, spongy bone, and compact bone) and that transfer among these compartments occurs through normal physiological processes. In addition, assumptions are made as to sources of environmental lead, along with other exposure and risk modeling components (USEPA, 1994c). As discussed in *Validation Strategy for the Integrated Exposure Uptake Biokinetic Model for Lead in Children* (USEPA, 1994e), it was necessary to verify the numerical accuracy of the model predictions through comparisons with real-world data.

The IEUBK model has been validated using paired data from measurements of lead in environmental media and blood-lead measurements in children (USEPA, 1994c). Ideally, site-specific estimates of blood-lead concentrations in children using the IEUBK model should be compared to empirical data collected from the population of interest at the site. In the absence of site-specific data on actual blood-lead levels for children at the site, it is important to note that the model may over- or underestimate blood-lead concentrations for the reasons discussed below.

Seasonal Fluctuations in Blood Lead Concentrations. Seasonal fluctuations in blood-lead concentrations as great as 4 to 6 µg/dL have been observed in some studies, and may be due to factors such as the relatively short half-life of lead in blood, reduced outdoor exposures in the wintertime, behavioral factors, and perhaps physiological (hormonal) changes (USEPA, 1994c). Given the likely differences in these factors for the potential future residential population and the sample population used to validate the IEUBK model, risks may be over- or underestimated.

Alternate Sources of Lead. The IEUBK model (USEPA, 1994c) predicts blood-lead concentrations in children based on current contributions from lead sources entered into the model. Existing body burdens of lead are not accounted for in the model. In addition, the amount of lead that a future potential residential receptor may be exposed to via intake of home-grown fruits and vegetables or the intake of lead-contaminated food or drugs was not quantified. Therefore, risks may be underestimated.

Socioeconomic Status. Blood-lead levels in two children with identical exposure scenarios may differ significantly as a result of the differences in family behavior patterns (USEPA, 1994c). For example, differences in socioeconomic status is known to be reflected in differences in household repair and cleaning, washing of children's hands and toys, food preparation methods, concern for balanced meals and improved nutritional status, more regular eating patterns, etc., all of which may impact blood lead levels. In the absence of site-specific data, risks may be over- or underestimated.

Variability in Child Blood Lead Levels. The variability in child blood-lead levels is represented in the IEUBK model by a single number: the GSD (geometric standard deviation). Ideally, the GSD should be based on actual measurements in the population of concern and an appropriate control population at the site. However, in the absence of site-specific measurements, the default GSD value used in the IEUBK model has been extrapolated from estimates for other populations. Uncertainties associated with extrapolating from surrogate populations include, but are not limited to, variability in exposure (level and pathways), biokinetics, socioeconomic and ethnic characteristics, degree of urbanization, and geographical locations.

Bioavailability of Lead. Per USEPA (1994c), bioavailability of lead from different sources may vary due to differences in lead concentration, speciation, particle size, and mineral matrix. In addition, physiological parameters such as age, nutritional status, time before or after a meal, and gastric pH contributes to the variability in blood-lead concentrations in children. Site-specific studies on bioavailability of lead from soils and dust, diet, water, and air reduce the uncertainties associated with blood-lead estimates. In the absence of site-specific *in-vivo* bioavailability studies, risks may be over- or underestimated.

Exposure Area and Frequency. The site boundary often is assumed to be representative of the future exposure area for a child resident. Given the paucity of data on future residential lot sizes and locations, risks may be over- or underestimated. In addition, it is assumed that a future child spends the majority of time at his/her residence. The model does not take into account the potential for increased or reduced exposures which may occur at parks, preschools, homes of babysitters, neighbors or relatives, or other locations frequented by the child.

APPENDIX C

RESULTS OF PARTICLE-SIZE AND BIOAVAILABILITY ASSESSMENTS

APPENDIX C

RESULTS OF PARTICLE-SIZE AND BIOAVAILABILITY ASSESSMENTS

C.1 INTRODUCTION

Appendix C is a summary of the soil particle size, *in vitro* lead bioavailability, and lead speciation results collected at two former small arms firing range sites in California and Texas and a skeet range site in Texas. Results from the former small arms firing range site in Alaska were not included because it was discovered that fly ash covered much of the range surface, which made it difficult to distinguish lead sources (e.g., bullet fragments or flyash). Site-specific information on soil particle size, *in vitro* lead bioavailability, and lead speciation results was obtained at each of these former small-arms firing ranges in order to obtain more technically defensible exposure estimates and cleanup levels.

This appendix consists of the following five sections and three attachments:

- Section C.1 Introduction
- Section C.2 Methods
- Section C.3 Results
- Section C.4 Conclusions
- Section C.5 References
- Attachment C.1 *In Vitro* Lead Bioavailability and Speciation Methods
- Attachment C.2 Lead Concentrations in Total Versus Sieved Soils
- Attachment C.3 *In Vitro* Lead Bioavailability Results

C.2 METHODS

Bioavailability of metallic lead has been shown to decrease with increasing particle size (Barltrop and Meek, 1979). There also is evidence to suggest that smaller soil particles (e.g., <100-250 μm) are more likely to be incidentally ingested than larger particles because the particles adhere more readily to the skin (Duggan *et al.*, 1985; Bornshine, *et al.*, 1987; Driver *et al.*, 1989; Sheppard and Evenden, 1994; Duff and Kissel, 1996; and Kissel *et al.*, 1996a). A conservative value of 250 μm in diameter is applied as an upper limit of bioavailable particle size by researchers at the University of Colorado (Drexler, 1997). Lead bioavailability also is expected to vary dependent on the chemical species present (from most to least bioavailable): lead carbonate > lead oxides > native or elemental lead > manganese/lead or iron/lead oxides and lead phosphates. Lead

concentrations in soil particle size fractions of <2.0 mm (i.e., total soil fraction) were compared with lead in the <250 µm particle size fractions. In addition, *in vitro* bioavailability and speciation of lead in the <250 µm soil fractions were determined.

C.2.1 Soil Particle Size and Lead Concentrations in Soil

As described in the Quality Program Plan (QPP) (Parsons ES, 1998), soil samples were sieved in the field to remove bullet fragments, lead shot, skeet target fragments, and/or shell casings that could interfere with laboratory analysis. Such larger fragments generally do not pose a risk via the human ingestion exposure route (due to the large particle sizes), but may significantly affect analytical results. Soil samples were processed by passing the soil through No. 4-mesh (4.75-mm) and No. 10-mesh (2.0-mm) stainless steel sieves in the field. The sample mass retained on each sieve for each sample was weighed in the field to determine the contributions of bullet fragments, lead shot, target fragments, and/or shell casings to contamination at the site. The weights of the total soil sample and of the fragments retained on each sieve, if any, were recorded on field sieve analysis forms and the fraction of soil passing through the No. 10 sieve was placed in sample containers provided by the laboratory. Samples not sieved in the field were placed directly into appropriate sample containers.

Laboratory chemical analyses were conducted in accordance with the QPP (Parsons ES, 1998). Field replicates were collected for at least 10 percent of the soil samples collected, and matrix spike/matrix spike duplicates were collected for at least 5 percent of the total samples.

To characterize the distribution of lead at the site, all of the samples in the <2.0 mm fraction (i.e., total soil fraction) were analyzed for total lead by trace inductively coupled plasma (ICP) spectroscopy using USEPA Method SW6010B. Selected samples also were analyzed for lead in the soil fraction passing through the 60-mesh (250 µm) sieve. Sample preparation involved sieving the sample through a No. 60-mesh sieve at the laboratory (Parsons ES, 1998). An aliquot of the sieved soil then was analyzed for lead per USEPA Method SW6010B.

C.2.2 Lead Bioavailability and Speciation

Per the Technical Review Workgroup (TRW) for lead (USEPA, 1996c), the fraction of lead in soil that is absorbed by the gastrointestinal tract (AF_s) is a product of the absorption factor for soluble lead ($AF_{soluble}$) and the relative bioavailability of lead in soil compared with soluble lead ($RBF_{soil/soluble}$) as shown in the following equation:

$$AF_s = AF_{soluble} \times RBF_{soil/soluble}$$

An *in-vitro* method for estimating $RBF_{soil/soluble}$ developed by Dr. John Drexler of Colorado University (CU) in Boulder, Colorado in conjunction with scientists from USEPA Region 8 was used. This *in-vitro* method incorporates a simple one-stage *in-vitro* digestion procedure that mimics absorption of lead from the gastrointestinal tract. *In-vitro* results have been shown to correlate well ($R^2 = 0.85$) with *in-vivo* swine study results (Medlin, 1997). The *in-vitro* method consisted of the following steps (refer to Attachment C.1 for a detailed discussion of methodology).

1. 250 mL of simulated stomach solution (37 °C) was added to 2.25 grams of a representative, dried and sieved (<250 μm) soil sample;

2. The flow of argon gas over the surface was initiated and after 10 minutes, stirring of the solution began at a rate of 60 rpm;

3. 5 mL samples were collected and filtered (<0.45 μm) 60 minutes after the simulated stomach solution was added to the soil sample;

4. The filtrate was analyzed for lead using ICP spectroscopy and USEPA Method 6010B; and

5. $RBF_{soil/soluble}$ was estimated by calculating the percent *in-vitro* bioavailability using the equation shown in Attachment C.1.

$RBF_{soil/soluble}$ is expected to vary significantly with particle sizes and lead speciation, both of which may vary from site-to-site. An analytical technique developed by CU's Department of Geological Sciences was used to determine the chemical species of lead in soil samples. Lead speciation analysis was conducted using an electron microprobe, which is similar to a scanning electron microscope, but with a multiple-band X-ray detector for determining the elemental composition of very small particles within a sample.

The lead speciation method consisted of the following steps (refer to Attachment C.1 for a detailed discussion of methodology).

1. Soil samples (<250 μm fraction) were prepared by adhering the soils onto disks using epoxy, and polishing the sample surfaces;

2. Microprobe measurements of individual particles were collected at statistically random locations across the sample surface, and the size of the largest-diameter particle, species of the particle, and association of the particle (whether it was "liberated" or "included" within another particle) were recorded for each location; and

3. The total mass and frequency of particle occurrence for each lead species in the samples were determined.

C.3 RESULTS

Site-specific information on soil particle size/lead concentrations and *in-vitro* relative lead bioavailability/speciation for surface and subsurface soil samples collected from the two small arms ranges and from the skeet range are summarized in the following subsections.

C.3.1 Soil Particle Size and Lead Concentrations in Soil

Concentrations of lead in the total surface soil fraction (i.e., No. 10 mesh [2.0 mm]-sieved soil samples) versus the <250 μm surface soil fraction (i.e., No. 60 mesh-sieved soil samples) for the skeet range and small arms range sites are shown in Figures C.1 and

C.2, respectively. Only surface soil sample results are shown in Figures C.1 and C.2 because this interval (0 to 0.5 feet [ft] below-ground-surface [bgs]) is the exposure interval for nonintrusive industrial/military workers. However, the tables in Attachment C.2 contain results for both surface and subsurface soil samples. Results from the small arms range sites were combined and plotted in Figure C.2 (refer to Attachment C.2 for results from each of the small arms range sites).

Lead concentrations in the skeet range total and <250 µm surface soil fractions ranged from 13 to 522 mg/kg and 14 to 680 mg/kg, respectively (Figure C.1 and Attachment C.2). Lead concentrations in the total and <250 µm surface soil fractions from the small arms range samples ranged from 9 to 51,700 mg/kg and 11 to 62,700 mg/kg, respectively (Figure C.2 and Attachment C.2). Lead concentrations in both the total and <250 µm soil fractions appeared to be lognormally distributed. Per USEPA (1992d) guidance, probability plots are useful graphical tools to test for normality/lognormality. Logarithmically-transformed lead concentrations in both total and <250 µm soil fractions from the small arms ranges and the skeet range fit linear regression curves of probability plots better than untransformed data, strongly suggesting lead concentrations were lognormally distributed (Figures C.3 and C.4).

Correlational analyses were conducted on lead concentrations (logarithmically-transformed) in the total and <250 µm surface soil fractions of samples collected from the skeet range (Figure C.5) and the small arms ranges (Figure C.6). There was a one-to-one linear correlation (within the 95-percent confidence interval on the regression curve) between log-transformed lead concentrations in the total versus <250 µm soil fractions at both skeet and small arms ranges. The regression correlation coefficients (R) for the skeet and small arms ranges were 0.97 and 0.87, respectively (Figures C.5 and C.6).

C.3.2 Lead Bioavailability and Speciation

In-vitro bioavailability results for surface soil samples collected from the skeet and small arms ranges are shown in Table C.1 (refer to Attachment C.3 for sample-specific results). The average *in-vitro* $RBF_{soil/soluble}$ value for lead in skeet range soils (Table C.1) was equivalent to the default $RBF_{soil/soluble}$ value (60-percent) recommended by the USEPA (1996c) TRW for Lead. Average *in-vitro* $RBF_{soil/soluble}$ values for lead in small arms range soils (81- and 85-percent) were greater than the 60-percent default $RBF_{soil/soluble}$ value recommended by USEPA's (1996c) TRW for lead.

Figure C.1
Lead Concentration in Soil Samples
from the Skeet Range

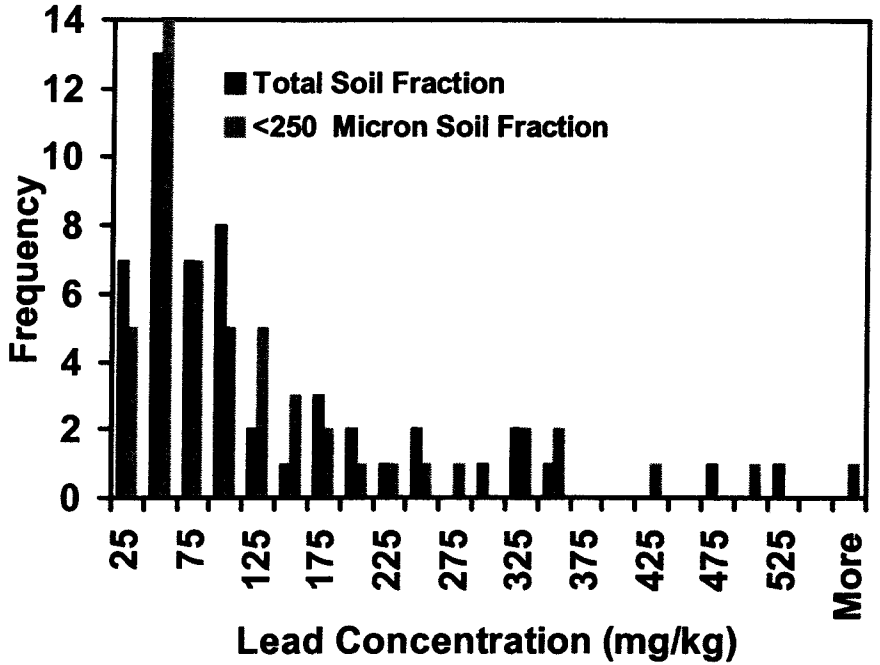

Figure C.2
Lead Concentrations in Soil Samples
from the Small Arms Ranges

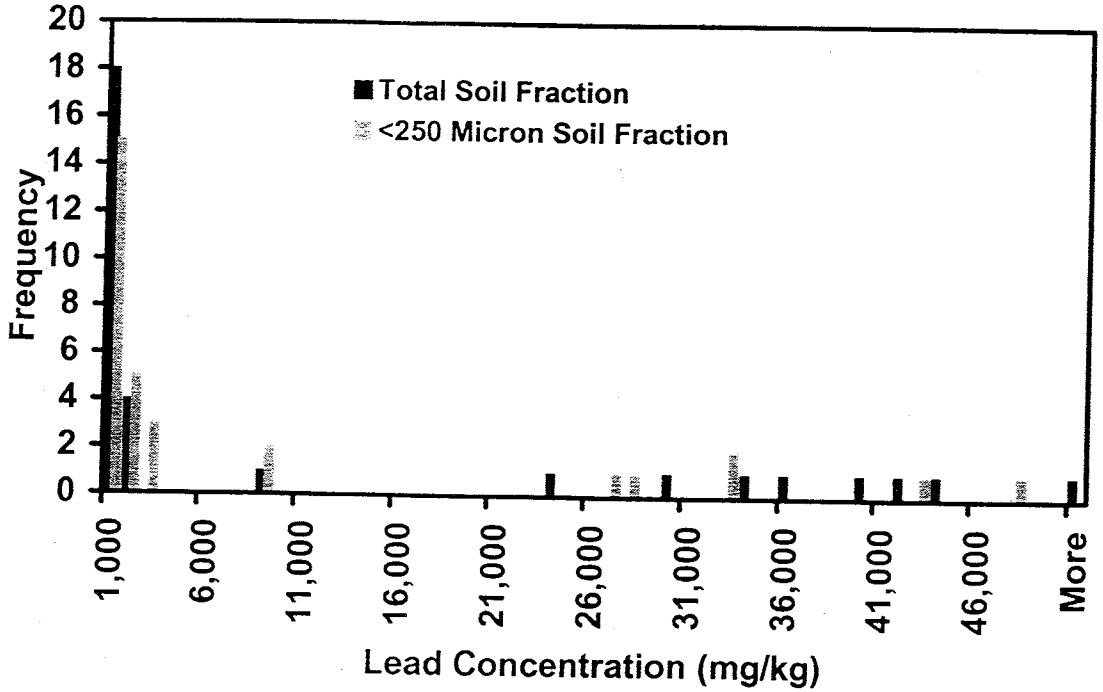

Figure C.3
Probability Plots of Untransformed
Lead Concentrations in Soil Samples
from the Skeet Range

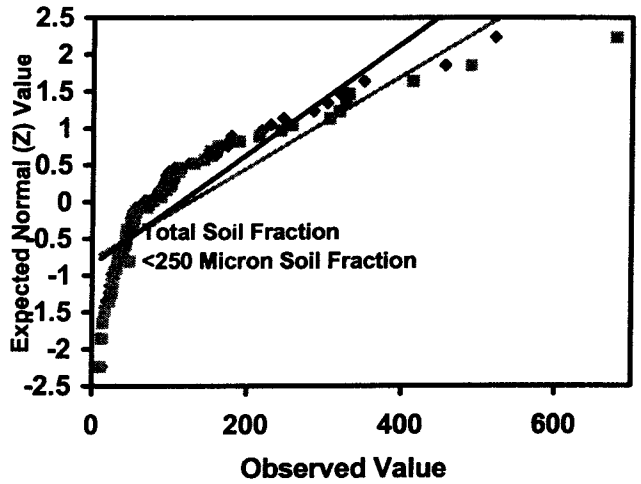

Figure C.3 (Continued)
Probability Plots of Log-Transformed
Lead Concentrations in Soil Samples
from the Skeet Range

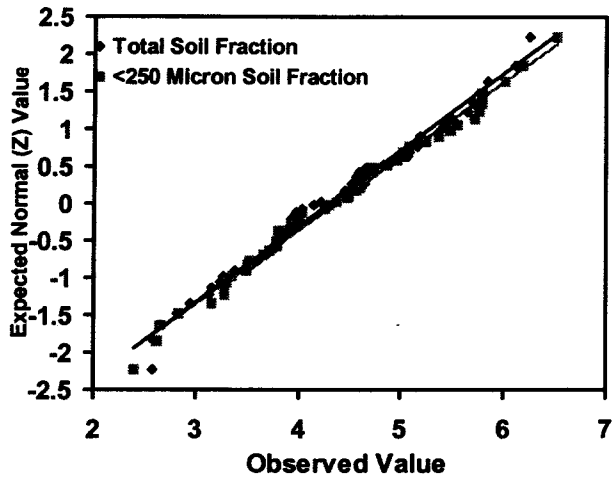

Figure C.4
Probability Plots of Untransformed
Lead Concentrations in Soil Samples
from the Small Arms Ranges

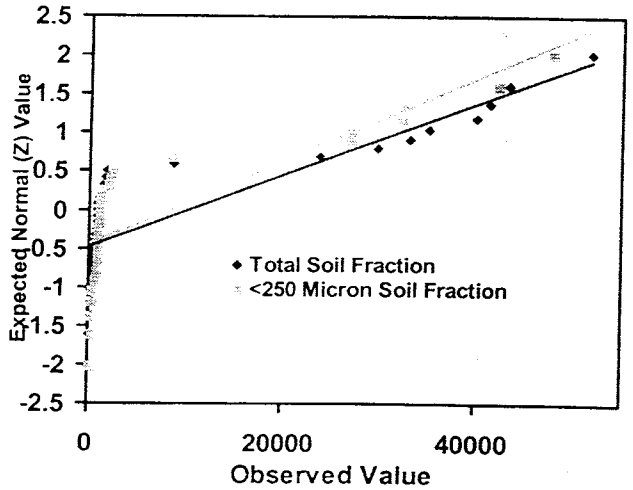

Figure C.4 (Continued)
Probability Plots of Log-Transformed
Lead Concentrations in Soil Samples
from the Small Arms Ranges

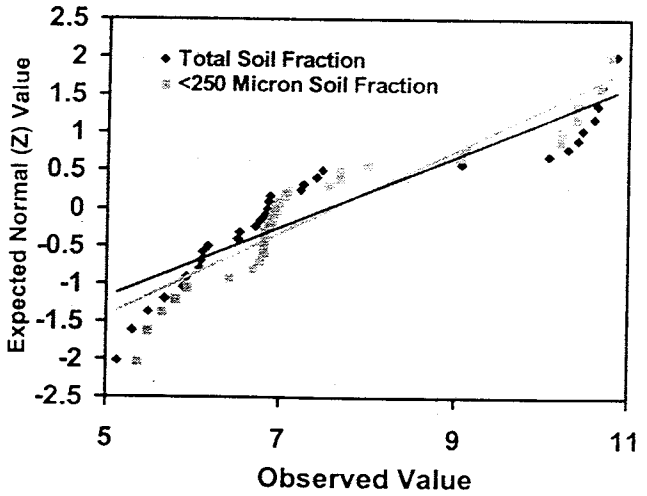

Figure C.5
Regression Curve of Log-Transformed
Lead Data from Skeet Range

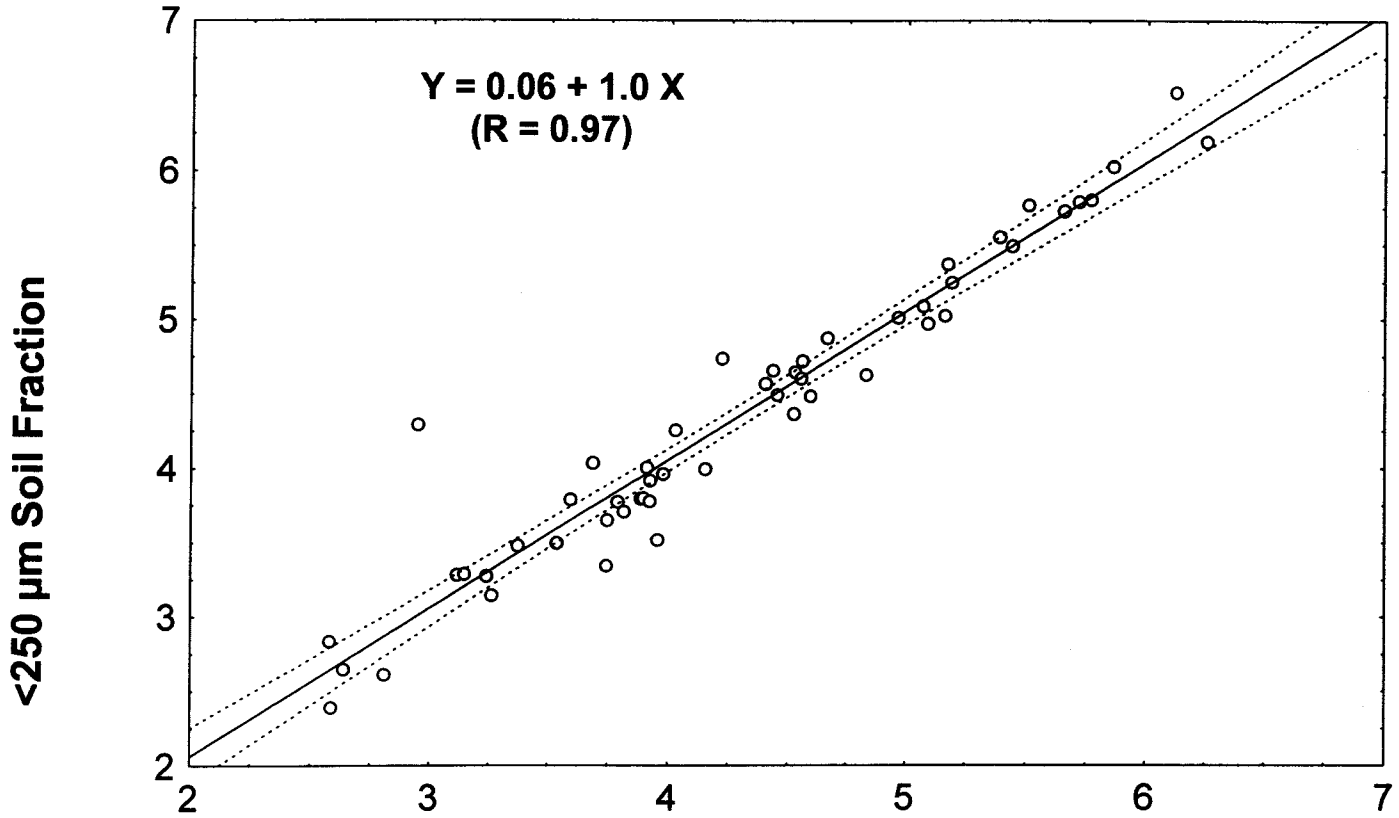

Figure C.5
Regression Curve of Log-Transformed
Lead Data from Small Arms Ranges

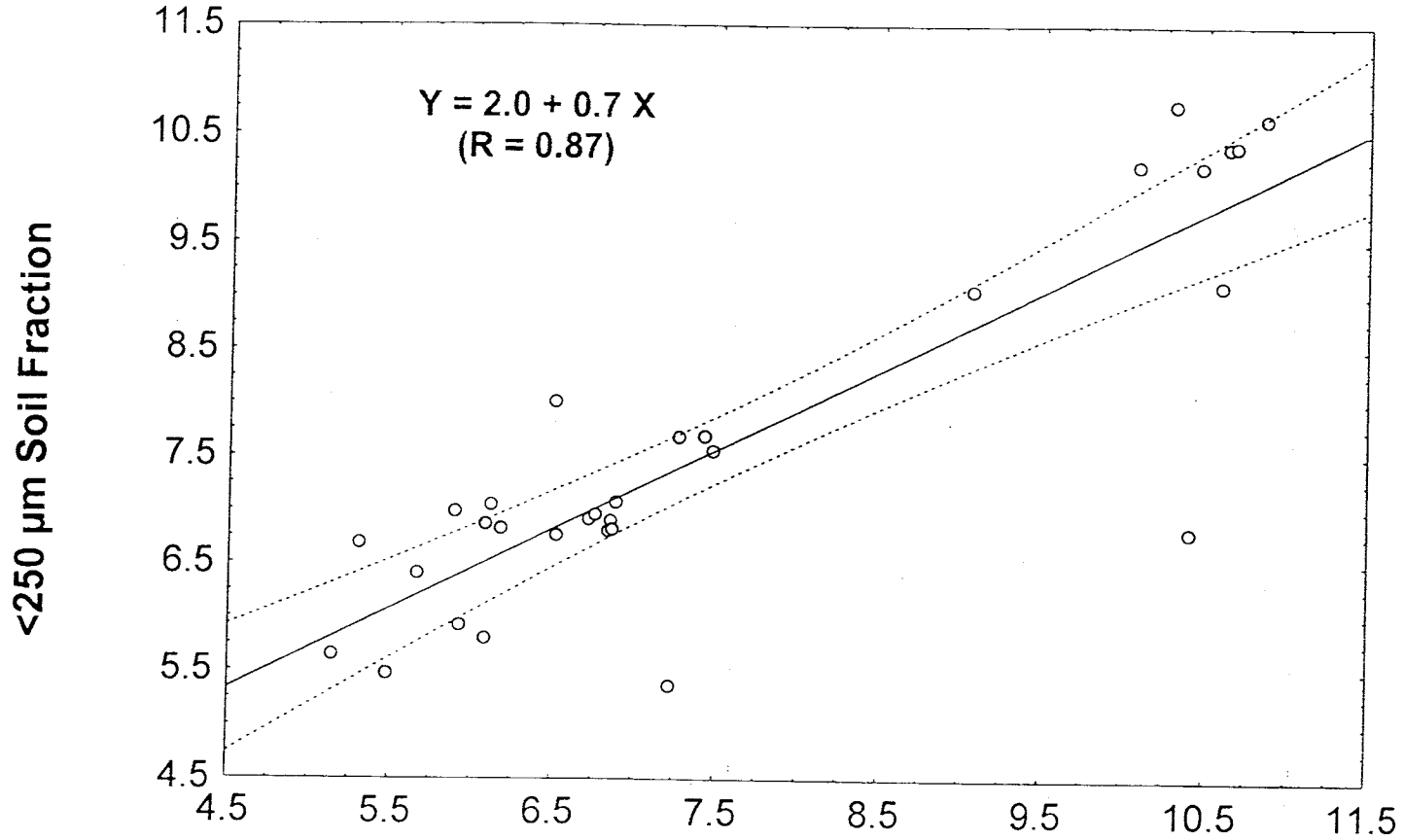

TABLE C.1
IN-VITRO BIOAVAILABILITY
PROTOCOL DOCUMENT
SMALL-ARMS FIRING RANGE DEMONSTRATION

		IN-VITRO BIOAVAILABILITY (Percent)		
Site	**N [a/]**	**Range**	**Average**	**SD[b/]**
Skeet Range	7	49-65	60	5.2
Small arms Range 1	5	75-96	85	10.3
Small arms Range 2	15	55-108	81	14.8

[a/] N = Total number of samples
[b/] SD = Standard deviation

Lead speciation results for surface soil samples (<250 μm fraction) collected from the skeet and small arms ranges are shown in Tables C.2 and C.3, respectively. As shown in Table C.2, the least bioavailable forms of lead (manganese-lead oxide and iron-lead oxide) were the predominant forms in skeet range samples, which correlated with the lower *in-vitro* bioavailability results for skeet range soil samples compared with small arms range samples. Lead carbonate was the predominant form in soil sample B from the small arms range, while oxides of lead, iron/lead, and lead/other metals were the predominant forms in samples A and C (Table C.3). The highly bioavailable lead carbonate level in sample B from the small arms range correlated with the greatest *in-vitro* bioavailability (96-percent; Table C.3). Lesser bioavailable lead oxides (compared with lead carbonate) in samples A and C from the small arms range corresponded with lower *in-vitro* bioavailability (79-percent; Table C.3).

C.4 CONCLUSIONS

Site-specific information on soil particle size/lead concentrations and *in-vitro* relative lead bioavailability/speciation was obtained for soil samples collected from three abandoned small-arms and skeet firing ranges. The purpose of collecting data on soil particle size, *in vitro* lead bioavailability, and lead speciation was to provide site-specific information that could be used in the remedial decision process in estimating technically defensible exposures and cleanup levels. The following conclusions were drawn based on a review of the site-specific results for soil particle size/lead concentrations and *in-vitro* relative lead bioavailability/speciation:

TABLE C.2
LEAD SPECIATION IN SURFACE SOIL SAMPLES FROM THE SKEET RANGE IN TEXAS
PROTOCOL DOCUMENT
SMALL-ARMS FIRING RANGE DEMONSTRATION

	Surface Soil Sample		
	A	B	C
In-Vitro bioavailability	61%	63%	59%
Total lead concentration	517 mg/kg	905 mg/kg	61 mg/kg
Lead Species (percent occurrence) [a/]			
Lead Carbonate (Cerussite)	<1	2	-- [b/]
Native Lead	--	--	--
Lead"M"Oxide [c/]	<1	2	--
Lead Oxide	--	2	--
Iron-Lead Oxide	11	13	39
Manganese Lead Oxide	82	60	61
$PbSiO_4$	<1	16	--

a/ Number of particles counted: 65, 102, and 5 for samples A, B, and C, respectively. Uncertainty with lead speciation data for sample C was relatively high because of the low particle count. Brass, which may contain trace amounts of lead, also was observed in samples A and B.

b/ "--" = not observed.

c/ "M" = one or more other metals (e.g., antimony and copper).

TABLE C.3
LEAD SPECIATION IN SURFACE SOIL SAMPLES FROM THE SMALL ARMS RANGE IN CALIFORNIA
PROTOCOL DOCUMENT
SMALL-ARMS FIRING RANGE DEMONSTRATION

	Surface Soil Sample		
	A	B	C
In-Vitro bioavailability	79%	96%	79%
Total lead concentration	2,085 mg/kg	8,119 mg/kg	1,076 mg/kg
Lead species (percent occurrence) [a/]			
Lead Carbonate (Cerussite)	22	52	<1
Native Lead	<1	3	<1
Lead"M"Oxide [b/]	41	16	33
Lead Oxide	16	-- [c/]	--
Iron-Lead Oxide	18	6	55
Manganese-Lead Oxide	--	11	5

a/ Number of particles counted: 97, 219, and 62 for samples A, B, and C, respectively. The following compounds, which may contain trace amounts of lead, also were detected: titanium dioxide, barium sulfate (barite), brass, and clays.

b/ "M" = one or more other metals (e.g., antimony and copper).

c/ "--" = not observed.

- Lead concentrations in the total (<2.0 mm) and <250 μm surface soil fractions at each of the firing range sites appeared to be lognormally distributed;

- There was an approximate one-to-one linear correlation between lead concentrations in the total soil fraction compared with the <250 μm soil fraction at each of the firing range sites;

- Lead concentrations (mg/kg) in the <250 μm soil fractions at each of the firing range sites were similar to concentrations measured in the corresponding total (<2.0 mm) soil fractions. This suggested that weathering of lead had occurred and that concentrations of lead similar to those measured in the total soil fraction also were present in surface soil particles (<250 μm) that are more likely to be incidentally ingested;

- Lead speciation results generally correlated with *in-vitro* bioavailability results; and

- Values for site-specific *in-vitro* relative bioavailability of lead in firing range soils, (i.e., estimates of human $RBF_{soil/soluble}$ values) were equivalent to or greater-than the default $RBF_{soil/soluble}$ value recommended by the USEPA (1996c) TRW.

ATTACHMENT C.1

IN-VITRO LEAD BIOAVAILABILITY AND SPECIATION METHODS

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1.0 OBJECTIVES

The objectives of this workplan are to determine the bioaccessability/bioavailability of lead forms identified in soils at DoD firing ranges. Parameters identified during the speciation analysis that are used to quantify bioaccessability include; particle size, associations, stoichiometry, frequency of occurrence of metal-bearing forms and relative mass of metal-bearing forms.

In addition, an *in vitro* technique, which has been calibrated to EPA Region VIII swine studies, will be used to establish bioavailability factors (BAF) for contaminated soils. These techniques, along with the methodology, instrument operation protocols, sample preparation, and QA/QC are discussed in the following sections.

2.0 BACKGROUND

To date numerous lead-bearing forms have been identified from various environments within mining districts, residential and industrial sites, (Emmons et al., 1927; Drexler, 1991 per. comm.; Drexler, 1992; Davis et al., 1993; Ruby et al., 1994; CDM, 1994; Weston, 1995). Table 2.1 contains those lead-bearing phases that would be most likely associated with a site contaminated by munitions use. This listing does not preclude the identification of other lead-bearing forms, but only serves as an initial point of reference. Many of these forms represent a series of minerals with varying metal concentrations (e.g. lead phosphate, Fe-Pb oxide, Mn-Pb oxide, and slag). Since limited thermodynamic information is available for many of these phases and equilibrium conditions are rarely found in soil environments, the identity of the mineral class (e.g. lead phosphate) will be sufficient and exact stoichiometry is not necessary.

TABLE 2.1
MOST PROBABLE LEAD-BEARING FORMS FOUND WITHIN FIRING RANGE SOILS

OXIDES	Lead oxide
	Manganese lead oxide
	Iron lead oxide
SULFATES	Iron lead sulfate
	Lead sulfate
CARBONATES	Lead carbonate
PHOSPHATES	Lead phosphates
OTHERS	Metallic Lead
	Lead paint
	Solder

It is important to know the particle-size distribution of metal-bearing forms in order to assess potential risk. It is believed that particles less than 250 mm (microns) are most available for human ingestion and/or inhalation (Bornshine, et al. , 1987). For this study the largest dimension of any one metal-bearing form will be measured and the frequency of occurrence weighted by that dimension. Although not routinely performed, particle area can be determined. It has been shown (CDM, 1994) that this data produces similar

results and area measurements only serve to add a considerable amount of time to the procedure thus limiting the total number of particles or samples that can be observed in a study.

Mineral associations may have profound effects on metal bioaccessability. For example; if a lead-bearing form in one sample is predominantly found within quartz grains while in another sample it is free in the sample matrix, the two samples are likely to pose significantly different risk levels to human health. Therefore, associations of concern include the following:

1. free or liberated,
2. inclusions within a second phase,
3. cementing or encrusting, and
4. alteration rims.

Bioavailability must be determined in order to access risk, to humans, from inhalation or ingestion of contaminated soils, based on the method of Medlin, 1997, and Medlin and Drexler, 1995. This method is designed to provide risk managers with site-specific BAF values for use in IEUBK model runs.

3.0 SAMPLE SELECTION

Samples should initially be selected based on available site characteristics. Additional samples may be collected if field investigations reveal new source areas. The methods and conditions of sample selection, collection, preservation, and representativeness are the responsibility of the contractor.

4.0 SCHEDULE

A schedule for completion of projects performed under this workplan will be provided in writing or verbally to the contractor along with monthly reporting requirements if large projects are performed. These schedules are based on an aggressive analytical program designed to ensure that the metals speciation analyses are completed in a timely period. Monthly reports are expected to reflect schedule status.

5.0 BIOACCESSABILITY

5.1 Instrumentation

Speciation analyses will be conducted at the Laboratory for Environmental and Geological Studies at the University of Colorado, Boulder. Primary equipment used for this work will include: Electron Microprobe (JEOL 8600) equipped with four wavelength spectrometers, energy dispersive spectrometer (EDS), BEI detector and the TN- 5600 data processing system. GELLER Dpic hardware for image storage and processing. An LEDC spectrometer crystal for carbon and LDE-1 crystal for oxygen analyses will be used.

5.2 Precision and Accuracy

The precision of the EMPA speciation will be evaluated based on sample duplicates analyzed at intervals of 10%, if more than 10 samples are run. The accuracy of the analyses will be estimated based on a number of methods depending on the source of the data. Data generated by the "EMPA point count" will be evaluated statistically based on the method of Mosimann (1965) at the 95% confidence level. It is very important that every attempt be made to insure that a minimum of 100-200 total particles are counted in order to provide a statistically meaningful particle count. If the contractor specifies, either the NIST 2710 or 2711 "Montana soils" can be speciated for traceability.

Quantitative elemental analysis, primarily performed on slag or other variable, metal-bearing forms, will have precision and accuracy evaluated on counting statistics and reproducibility of NIST or other certified standards using conventional EMPA methods. In general, site-specific concentrations for these variable, metal-bearing forms will be determined and compiled. Average concentrations will then be used for further calculations. Data on specific gravity will be collected from referenced data bases or estimated based on similar compounds.

5.3 EMPA Methodology

5.3.1 Sample Preparation

The minus 250 mm size fraction of sample will be used for metal speciation. Grain mounts, 1.5 inches in diameter, of each sample will be prepared using air-cured epoxy. The grain mounting procedure involves the following:

1. Logging the samples of which polished mounts will be prepared.
2. Inspection of all plastic cups, making sure each is clean and dry.
3. Labeling each "mold" with its corresponding sample number.
4. All samples will be split to produce a homogeneous 1-4 gram sample.
5. Mixing epoxy resin and hardener according to manufacturer's directions.
6. Pour 1 gram of sample into mold. Double checking to make sure sample numbers on mold and sample match. Pouring epoxy into mold to just cover sample grains.
7. Using a new wood stirring stick with each sample, carefully blend epoxy and grains so as to coat all grains with epoxy.
8. Setting molds to cure at ROOM TEMPERATURE in a clean restricted area. Adding labels with sample numbers and covering with more epoxy resin. Leaving to cure completely at room temperature.
9. One at a time, removing each sample from its mold and grinding flat the back side of the mount.

10. Using 600 grit wet abrasive paper stretched across a grinding wheel for removing the bottom layer and exposing as many mineral grains as possible. Follow with 1000 grit paper.

11. Start polishing with 15 mm oil based diamond paste on a polishing paper fixed to a lap. Using paper instead of cloth minimizes relief.

12. Next use 6 mm diamond polish on a similar lap.

13. Finally polish the sample with 1 mm oil based diamond past on polishing paper. Followed by . 05 mm alumina in water suspension. The quality should be checked after each step. Typical polishing times are 30 minutes for 15 mm, 20 minutes for 6 mm, 15 minutes for 1 mm and 10 minutes for 0. 05 mm.

NOTE: use low speed on the polishing laps to avoid "plucking" of sample grains.

14. Samples should be completely cleaned in an ultrasonic cleaner with isopropyl alcohol or similar solvent to remove oil and finger prints.

15. To insure that no particles of lead are being cross contaminated with sample preparation procedures, a blank (epoxy only) mold will be made following all of the above procedures. ***At least one blank will be prepared for the project samples.*** This mold will then be speciated along with the other samples.

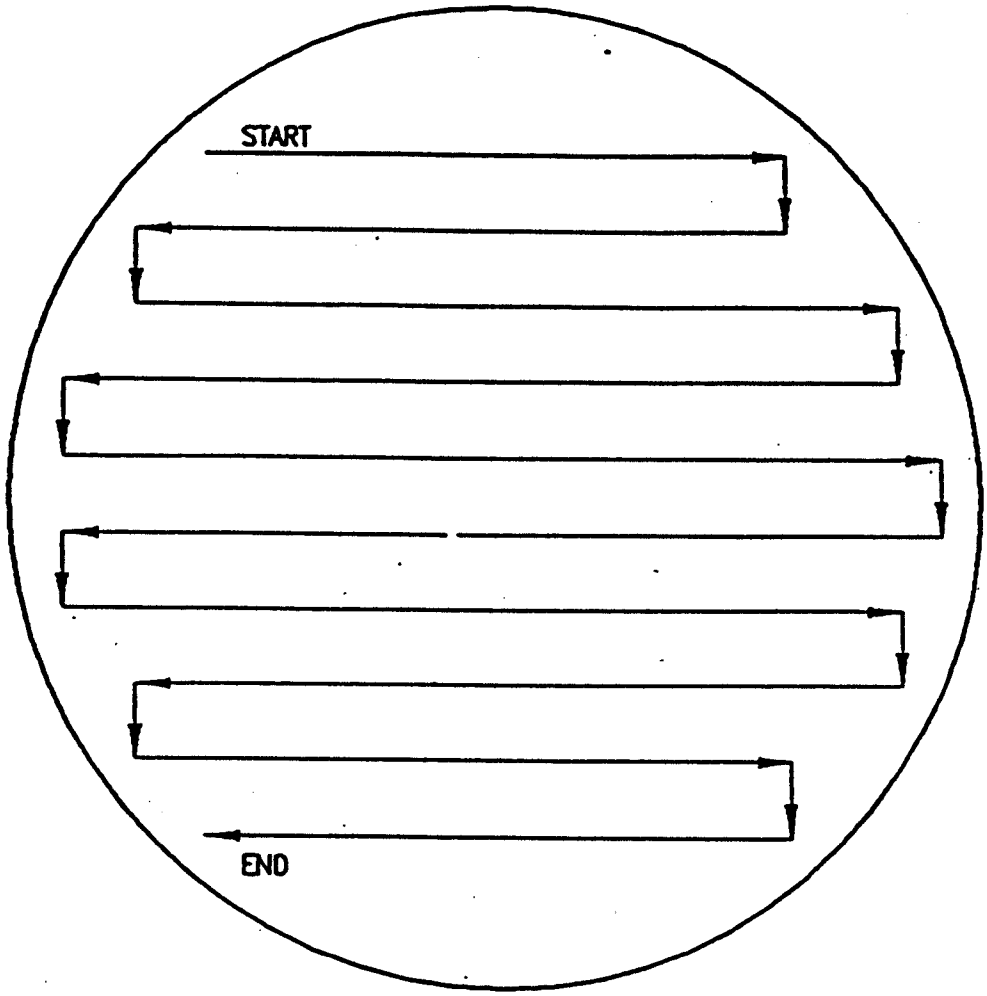
16. Each sample be carbon coated. Once coated the samples should be stored in a clean, dry environment with the carbon surface protected from scratches or handling.

5.3.2 Point Counting

Counts are made by traversing each sample from left-to-right and top-to-bottom as illustrated in Figure 5.1. The amount of vertical movement for each traverse would depend on magnification and CRT (cathode-ray tube) size. This movement should be minimized so that NO portion of the sample is missed when the end of a traverse is reached. Two magnification settings generally are used. One ranging from 40-100X and a second from 300-600X. The last setting will allow one to find the smallest identifiable (1-2 micron) phases. The portion of the sample examined in the second pass, under the higher magnification, will depend on the time available, the number of metal-bearing particles, and the complexity of metal mineralogy. A maximum of 8 hours will be spent per sample.

5.3.3 Data Presentation

Analyst will record data as they are being acquired from each using the LEGS software, which places all data in a spreadsheet file format, Figure 5.2. Columns have been established for numbering the metal-bearing phase particles, their identity, size of longest dimension in microns, along with their association (L=liberated, C=cementing or encrusting, R=rimming, I=included). The analyst may also summarize his/her measurements and observations in the formatted data summary files.



FIRST PASS AT 40–100 X
SECOND PASS AT 300–600 X

METALS SPECIATION WORK PLAN	SYSTEMATIC TRAVERSE OVER SPECIATION SAMPLE MOUNTS FOR POINT COUNTING	Figure 5.1

Figure 5.2

DATA ACQUISITION SHEET

ASSAY (ppm): _____

SAMPLE I.D.: _____ LAB: _____

ANALYST: _____ TIME END: _____

TIME START: _____

DATA ACQUISITION SHEET

NOTES	Identity	Size		Liberated	Inclusions	Encrusted Intergrown Cemented	Rim
		Length (um)					

The frequency of occurrence and relative metal mass of each metal-bearing form as it is distributed in each sample will be depicted graphically as a frequency barograph. The particle size distribution of metal-bearing forms will be depicted in a histogram. Size histograms of each metal-bearing form can be constructed from data in the file.

5.3.4 Analytical Procedure

Prior to EMPA examination a brief optical examination of each sample will be made. This examination may help the operator by noting the occurrence of slag and/or organic matter.

Standard operating conditions for quantitative and qualitative analyses of metal-bearing forms are given in Table 5.1. Quality control will be maintained by analyzing standards at regular intervals and duplicates (see next section).

TABLE 5. 1
EMPA STANDARD OPERATING CONDITIONS

	WDS	EDS
Accelerating Voltage	15 KV	15-20 KV
Beam Size	1-2 microns	1-2 microns
Cup Current	10-30 NanoAmps	10-30 NanoAmps
Ev/Channel	NA	10 or 20
Stage Tilt	NA	Fixed
Working Distance	NA	Fixed
MCA time Constant	NA	7. 5-12 microseconds
X-ray lines**	S K-alpha PET O K-alpha LDE1 C K-alpha LDEC Zn K-alpha PET As L-alpha TAP Cu K-alpha LIF Cd L-alpha PET Pb M-alpha PET Pb L-alpha LIF	S K-alpha 2. 31 KeV O K-alpha 0. 52 KeV C K-alpha 0. 28 KeV Pb M-alpha 2. 34 KeV Pb L-alpha 10. 5 KeV Mo K-alpha 17. 5 KeV Zn K-alpha 8. 63 KeV Cu K-alpha 8. 04 KeV As K-alpha 10. 5 KeV As L-alpha 1. 28 KeV Cd L-alpha 3. 13 KeV

** X-ray lines for other elements are selected for maximum intensity and minimum spectral overlap.

The backscattered electron images will be examined using two settings: one for light-element matrices (slag or organic) and the second for heavy-element matrices (lead sulfide or lead carbonate etc.).

Thus, no metal-bearing minerals will be missed during the scanning of the polished grain mount. The scanning will be done manually in a manner similar to Figure 5. 1. Typically, the magnification used for scanning all samples except for airborne samples will be 40-100X and 300-600X. The last setting will allow the smallest identifiable (1-2 mm) phases to be found. Once a candidate particle is identified, then the backscatter image will be optimized to discriminate any different phases that may be making up the particle or defining its association. Identification of the metal-bearing phases will be done using both EDS and WDS on a EPMA, with spectrometers peaked at S, M(metal of concern), O, and C. The size of each metal-bearing phase will be determined by

measuring in microns the longest dimension. A maximum of 8 hours will be spent in scanning and analyzing each mount.

Quantitative analyses

Quantitative analyses are required to establish the average metal content of the metal-bearing minerals, which have variable metal contents as: Fe-(M) sulfate, Fe-(M) oxide, Mn-(M) oxide, organic, and slag. These determinations are important, especially in the case of slag which are expected to have considerable variation in their dissolved metal content. Results will be analyzed statistically to establish mean values. They may also be depicted as histograms to show the range of metal concentrations measured as well as the presence of one or more populations in terms of metal content. In the latter case, non-parametric statistics may have to be used or the median value has to be established.

Associations

The association of the metal-bearing forms will be established from the backscattered electron images. Particular attention will be paid in establishing whether the grains are totally enclosed, encapsulated or liberated. The rinds of metal-bearing grains will be identified. Representative photomicrographs of backscatter electron images establishing the association of the principal metal-bearing forms will be obtained for illustration purposes. A positive/negative, black and white film (Polaroid 55) will be used or a 128x128 (minimum) binary image in TIFF format may be stored. Recorded on each photomicrograph and negative will be a scale bar, magnification, sample identification and phase identification.

5.3.5 Instrument Calibration and Standardization

At the beginning of each analytical session the WDS will have spectrometers "peaked" for M (metal of concern), C, O, and S on the appropriate crystals using mineral standards. The EDS will have MCA (multi-channel analyzer) calibrated for known peak energy centroids. Calibration will be made so as to have both a low (1. 0-3. 0 KeV) and a high (6. 0-9. 0 KeV) energy peaks fall within 0. 05 KeV of its known centroid.

Once a week the magnification marker on the instrument will be checked following manufacturer instructions or by measurement of commercially available grids or leucite spheres. Size measurements must be within 4 microns of certified values.

Daily standardization for all elements is not essential. Visual verification of an element such as phosphorous or silica from an EDS spectra will be sufficient. However, due to the spectral overlaps encountered by (Pb-S-Mo) and (As-Mg-Pb) and the difficulty in detecting oxygen and carbon it will be important to check their standardization routinely.

At the beginning of each analytical session or once every 24 hours a set of mineral or glass standards will be run quantitatively for M (metal of concern), S, O, and C. If elemental quantities do not fall within +/- 5% of certified values the element must be recalibrated.

The metal-bearing forms in these samples will be identified using a combination of EDS, WDS and BEI. Once a particle is isolated with the backscatter detector, a 5 second EDS spectra is collected and peaks identified. The count rates for M (metal of concern), S, C, and O can be either visually be observed on the wavelength spectrometers or k-ratios calculated.

5.3.6 Archival of Data

An example data summary file is presented in Figure 5.3. The laboratory is able to archive 100% of all EDS spectra and particle images; however, this is generally not done and only a representative population of metal-bearing particle images, and spectra are stored.

6.0 BIOAVAILABILITY

6.1 *In Vitro* Methodology

In this study, a simple one stage *in vitro* digestion procedure is used to mimic absorption of lead from the GI tract: Stage I, the stomach phase (Table 6. 1). Stage II, the intestinal phase, has also been developed, but is not required for testing the bioavailability of lead. Adequate correlation with EPA Region VIII swine studies has been obtained for lead using just the stomach phase.

TABLE 6.1
SUMMARY OF *IN VITRO* EXPERIMENTAL PROCEDURE (STOMACH PHASE)

Step	Operation
1	Weigh out 2.25 g of representative, dried & sieved (<250 μm) test sample.
2	Add 250 mL stomach solution (Table 6.2) & weighed test sample to reaction vessel.
3	Place vessel in heated water bath (37°C).
4	Turn on argon gas over exposed surface.
5	After 10 minutes, turn on stirring rod.
6	Collect and filter (< 0.45 μm) 5 mL samples with disposable syringe at 60 minutes after start of experiment.

Step 1 - Soil Sample

A representative site sample should be chosen if only one sample is to be run; otherwise a larger array of samples should be run to provide a statistically meaningful bioavailability factor (BAF) for a particular site. Metal content ***(determined by inductively coupled plasma using EPA's SW-846 Method 6010B)*** of each pre-*in vitro* solid sample must be known to calculate the BAF after the experiment is done. Weigh out a 2.25 ± 0. 01 g split of dried and sieved (<250 μm , Nalgene sieve) sample. This size range was used in the corresponding EPA *in vivo* study to represent the size fraction that may adhere to a child's hands, clothes, toys, etc. This particle size is also used in this *in vitro* experiment. However in the future the test particle size fraction may need to be lower or higher. For example, the >150 μm size fraction may adhere to hands when

1.Sample #: L-79 B1 LST 01 911109 Pb Assay: 4 570 Type: SOIL Lab: SSW

2. Minerals		Chemical Formula	Freq.	T Area, μm^2	Area, %	Freq.* = Length		
						Total, μm	L, %	med.
Galena:	Ga	PbS						
Anglesite:	Ang	$PbSO_4$	8			68.69	0.62	8.39
Cerussite:	Cer	$PbCO_3$	123			5222.63	46.85	19.85
Pb oxide:	PbO	Pb_xO_y						
PbO/carbonate:	PbO?							
Metallic Pb:	Pb	Pb						
Pb phosphates:	PbPhos		44			2554.16	22.91	33.71
Pb-Fe sulphate:	PbFeSul							
Pb arsenate:	PbArs							
Pb vanadate:	PbVan							
Wulfenite:	Wulf	$PbMoO_4$						
Mn-Pb oxide:	MnPbO		31			2915.87	26.16	42.58
Fe-Pb oxide:	FePbO							
Pb-bearing barite:	PbBar							
Slag:	Slag		2			385.71	3.46	192.86
Pb silicate:	PbSi							
Pb-bearing C-matter	Pb(org)							
Paint:	Pnt							
Solder:	Sold							
Pb sulfosalt:	PbSfs							
Pb antimonate:	PbAnt							

3. Association:
Cerussite is liberated (100), enclosed (13) in silicate, FeO or silicate aggregates or intergrown with or cementing (10) quartz, silicate, Fe-sulphate or FeO. PbPhos is liberated (28), intergrown with or cementing (12) FeO, MnPbO or silicate or enclosed (4) in silicate aggregates. MnPbO is intergrown with or cementing (16) FeO, silicate or quartz, enclosed (12) in silicate aggregates or liberated (3). Anglesite is enclosed (6) in silicate or liberated (2). Slag is liberated.

4. Pb Mineralogical Distribution: VALIDATED 10/4/93 (LT)

5. Species Bearing Ag x; As □; Bi □; Cd □; Hg □; Se □; Tl □ Observed

Signature of Analyst: Wendy Lee 10/4/93

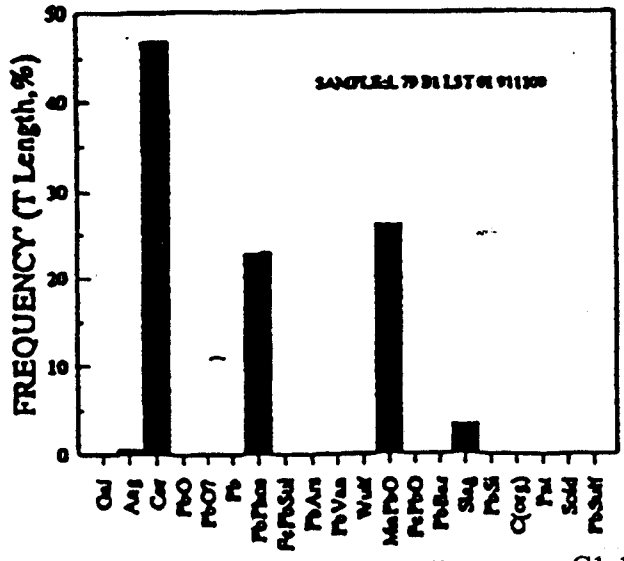


Figure 5.3
Data Summary File

moisture content exceeds 10%; however if soil is dry, then <65 μm seem to adhere the strongest. Other factors may also play a role in evaluating the adherence of a particular soil to the skin, such as relative humidity, soil temperature, organic matter, clay and mineral content, and single soil exposure vs. continuous exposure. An equation describing the "concentration enrichment" due to increased surface area of smaller particles might be applicable to some exposure situations.

Step 2 - Reaction Vessel

The "stomach" is a specially designed polypropylene cylinder. Each cylinder holds 250 mL of simulated gastric juice (Table 6.2) and 2.25 g of contaminated test sample. The stomach acts as a reservoir to receive all the food at once, while delivering it to the intestine in intervals; though gastric emptying can occur rapidly depending on the physiological state of the ileum. In the reaction vessel, combine 2.25 g test sample and 250 mL stomach solution. This ratio of 2.25g:250 mL has been arbitrarily chosen. Research has shown that an average 2 - 3 year old child may ingest 80 - 200 mg soil day^{-1}. However, as little as 1 - 2 mg day^{-1} for 5 - 6 months could cause lead poisoning in a 1 - 2 year old. The average stomach can hold approximately 1 L of fluid; whereas the entire digestive tract can secrete and absorb up to 10L of fluid per day. The *in vitro* "stomach" holds 0.25L fluid. The synthetic stomach solution is prepared by adding pepsin and various stomach acids to 4 L of deionized water (Table 6. 2).

TABLE 6.2
COMPONENTS OF *IN VITRO* SIMULATED STOMACH SOLUTION

(Note: all chemicals from Sigma Chemical Co. , St. Louis, MO, unless otherwise noted).

Amount	Compound
5 g	pepsin A (from porcine stomach mucosa; EC 3. 4. 23. 1)
2 g	citric acid anhydrous (Fisher Sci, NJ; USP $C_6H_8O_7$; FL-03-0791)
2 g	DL -malic acid (DL - hydroxybutanedioic acid; $C_4H_6O_5$; 617-48-1)
1. 68 mL	DL -lactic acid (C3H6O3, synthetic: 85% (w/w) syrup approx. 98%)
2 mL	acetic acid glacial (Amer. Sci. Prod., IL; CH_3COOH; UN2789)
variable	hydrochloric acid (trace metal grade) to bring to pH of 1. 5

The human stomach secretes hydrochloric acid (HCl), by parietal cells in the gastric epithelial mucosa, and the enzymes: pepsin by chief cells, renin, and lipase which help digest carbohydrates, proteins and fats. Other acids that have been incorporated into the *in vitro* stomach fluid are: malic acid, citric acid, lactic acid, and acetic acid.

The average pH of the stomach can range from as low as 1 to as high as 6, depending on food content and physical health of the subject. The pH of the stomach is an important parameter for bioavailability assessment. The usual pH of a fasting child is around 1 - 1.5; a higher pH, more typical of a stomach with food in it, is expected to lower the resulting bioavailability of ingested lead because the solubility of Pb decreases with increasing pH. The pH of the *in vitro* stomach solution is continuously monitored throughout the duration of the experiment; a few drops of HCl can be added if necessary

to keep the pH down (especially for "slag" samples which tend to increase in pH when added to stomach solution).

Step 3 - Heat

The solution is heated in a water bath to 37°C (~98. 6°F) before the sample amount is added. The reaction vessel remains in this heated environment for the entire run of the experiment. This parameter mimics that of normal internal body temperature.

Step 4 - Argon

Turn on argon gas (or any inert gas) over the exposed surface of the reaction vessel to avoid any unnatural or excessive formation of oxidation complexes during the experiment.

Step 5 - Stirring rod

The time the sample stays in the mouth, throat, and esophagus is equated to the 10 minutes before the stirring rod is turned on in the experiment. In the mouth, salivary glands secret a mucus that aids in mechanical digestion and dissolving of food. The throat and esophagus transport these contents into the stomach.

The stirring rate of this particular *in vitro* experiment is 60 rpm (Arrow 1750 motor; Arrow Engineering Co., Inc. , Hillside, N.J.). The stirring rate needs to be vigorous enough to keep particles in suspension, but not too vigorous as to overestimate the mechanical digestion process in the digestive tract. In mechanical digestion, solid food mixes with various juices from the digestive glands to dissolve the food as much as possible before chemical digestion occurs.

Step 6 - Sampling Events

Collect and filter 5 mL samples at 60 minutes after the start of experiment. Temporarily turn off the stirring rod to collect samples. Replace the volume of solution removed at each sampling with 5 mL of stomach solution to maintain a constant volume in the remaining experiment. Collect samples with disposable 5cc sterile syringes (Becton Dickinson; Franklin Lakes, New Jersey), filter with disposable 0.45 µm cellulose acetate filters (Microfiltration Systems; Dublin, CA), and store in disposable 10 mL centrifuge tubes. The pipettes, filters, and storage tubes are used only once to minimize any contamination from recycled labware. Analyze samples for metals on an ***ICP using EPA Method 6010B.***

QA/QC consists of 10% of samples run as duplicate ***and lead acetate spikes*** through the *in vitro* experiment, as well as a spike, duplicate, blank, and standard every 10% of samples run on the ICP-AES.

Calculation of Bioavailability Factor (BAF)

The amount of Pb^{2+} found in solution from sampling the stomach phase is used to calculate the percent bioavailability (% BAF) of lead. Typically, it is in the small intestine that absorbs lead across the human GI tract; however some fraction of this Pb^{2+} is likely to be excreted via the bile duct before entering the systemic circulation.

The following equation is used to calculate the bioavailability factor (% BAF):

$$\%BAF = \left\{ \frac{(L)(M_{aq})}{\frac{(S)(M_s)}{1000}} \right\} x\,100$$

L = volume of stomach solution : 0.25 L (constant) (density of stomach solution is 1)

M_{aq}= amount of Pb^{2+} in stomach solution samples [mg kg^{-1}]; (measured by ICP-AES)

S = weight of initial soil sample: 2 25 g (constant);

M_s = amount of metal in initial bulk soil sample [mg kg^{-1}]; (measured by ***ICP-AES***).

The % BAF is not a measure of the absolute bioavailability of lead in a system; it is a measure of relative bioavailability. However, this relative %BAF can be used to calculate the absolute bioavailability of a metal phase in any biological system. The %BAF calculated directly from the *in vitro* experiment can be thought of as 100% lead absorption. The absolute bioavailability for a particular human system will always be less than this 100% absorption. For instance, adults are thought to absorb 5 - 15% of the lead ingested; to calculate the absolute BAF from a lead-dosed sample, the "relative BAF" is multiplied by a factor of 0.05 to 0.15. For a 5-year-old child, the relative BAF is multiplied by 25%; and for an infant the multiplying factor is 50%. These coefficients represent the expected absorption amounts of lead from the gastrointestinal tract (default values for lead absorption in the EPA's blood Pb estimation model, IEUBK, are: 50% for dissolved Pb, and 30% for Pb in soil). In general, infants may absorb 5 times more lead than adults, and 2.5 times more than older children.

Reproducibility of the *In vitro* Method

To test the reproducibility of the *in vitro* method, a NIST standard, MS 2710, was run through the stomach phase six separate times. This sample, "Montana Soil 2710" (Trahey, 1995), is a very fine-grained, homogenous soil with 5532 ppm Pb ± 80 ppm; and 626 ppm As ±38 ppm. In addition to testing reproducibility, the uncertainty of the *in vitro* method was examined by calculating: the average relative percent difference [RPD = (a-b)/((a+b)/2)] of duplicate pairs (n=98 pairs); the average relative percent difference of spiked (spike: 20 ppm Pb) sample pairs (n=113 pairs); and the average relative percent difference of 79 "post" *in vitro* samples analyzed on the ICP-AES.

7.0 FINAL REPORT

A final laboratory report will be provided by the Contractor. The report will include all EMPA data including summary tables and figures. Individual sample data will be provided on disk.

Speciation results will include: 1) A series of tables summarizing frequency of occurrence for each metal phase identified along with a confidence limit, 2) Summary histograms of metal phases identified for each waste type, 3) A summary histogram of

particle size distribution in each waste type, and 4) A summary of metal phase associations. Representative photomicrographs or TIFF images will also be included in the final report.

In vitro results will be provided in tabular form listing; sample weights, and ICP results along with BAF values for each sample.

8.0 PERSONNEL RESPONSIBILITY

The analysts will carefully read the standard operating procedure prior to any sample examination. It is the responsibility of the lab supervisor and designates to ensure that these procedures are followed, to examine QA and replicate standards, and to check EDS, WDS ***and ICP*** calibrations. The laboratory supervisor will collect results, ensure they are in proper format, and deliver them to the contractor.

Monthly reports summarizing all progress, with a list of samples speciated and ***in vitro analysis*** performed each month.

It is also the responsibility of the laboratory supervisor to notify the contractor representative, of any problems encountered in the sample analysis procedure.

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ATTACHMENT C.2

LEAD CONCENTRATIONS IN TOTAL VERSUS SIEVED SOILS

TABLE C.2-1
SUMMARY OF LEAD CONCENTRATIONS IN SOIL SAMPLES FROM THE CALIFORNIA SMALL ARMS RANGE

TOTAL SOIL FRACTION

Sampling Location and Associated Lead Concentration (mg/kg)[a/]

Sample Depth Interval (feet bgs)[b/]	RBS-1	RBS-2	RBS-3	RBS-4	RBS-4 (replicate)	RBS-5	RBS-6	RBS-7	RBS-8	RBS-9	RBS-10
0.0 - 0.25	1,670 J[c/]	858 J	8,650 J	1,760 J	976 J	955 J	39,900 J	677 J	945 J	824 J	374
0.5 - 1	85.9 J	368 J	986 J	1,010 J	2,750 J	201 J	11,500 J	122 J	532 J	31.5 J	39.6
1.5 - 2	17.1 J	13.4 J	27.1 J	236 J	384 J	217 J	207 J	43.9 J	17.9 J	14.9	13.7
2.5 - 3	24.8 J	9.4 J	30.5 J	21 J	41.4 J	36 J	33.8 J	72.9 J	39.3 J	11.2	10.5

SIEVED SOIL FRACTION (≤250μm[d/])

Sampling Location and Associated Concentration (mg/kg)

Sample Depth Interval (feet bgs)	RBS-1	RBS-2	RBS-3	RBS-4	RBS-4 (replicate)	RBS-5	RBS-6	RBS-7	RBS-8	RBS-9	RBS-10
0.0 - 0.25	2170 J	1,040 J	8,520 J	1,890 J	1,170 J	909 J	8,950	857	983	999	371 J
0.5 - 1	192 J	653 J	1,310 J	1,530 J	1,430 J	364 J	8,710	179	318	55.9	56.3 J
1.5 - 2	203 J	41.6 J	127 J	937 J	434 J	288 J	528	74.6	20.3	17.7 J	15 J
2.5 - 3	157 J	27.2 J	83.6 J	148 J	1,070 J	233 J	278	37.2	31.5	15.1 J	10.3 J

a/ mg/kg - milligrams per kilogram.

b/ feet bgs - feet below ground surface.

c/ "J" = value is an estimated concentration.

d/ μm - microns.

TABLE C.2.2
COMPARISON OF LEAD CONCENTRATIONS IN TOTAL AND SIEVED FRACTION SOIL SAMPLES FROM THE TEXAS SMALL ARMS RANGE

Sample Location	Sample Depth Interval (feet bgs)[b]	Soil Fraction and Associated Concentration (mg/kg)[a]	
		(Total Fraction)	(Sieved Fraction)
SS02	0.0 - 0.5	201 J[c]	798
SS07	0.0 - 0.5	1,430 J	2,150
SS15	0.0 - 0.5	930 J	893
SS17	0.0 - 0.5	51,700 J	42,100
SS19	0.0 - 0.5	451 J	1,140
SS24	0.0 - 0.5	438 J	328
SS25	0.0 - 0.5	33,100 J	897
SS38	0.0 - 0.5	29,800 J	47,700
SS44	0.0 - 0.5	361	1,070
SS45	0.0 - 0.5	480 J	914
SS51	0.0 - 0.5	43,200 J	32,600
SS57	0.0 - 0.5	668 J	2,980
SS64	0.0 - 0.5	41,300 J	32,200
SS65	0.0 - 0.5	23,900 J	27,200
SS65 (Rep)[d]	0.0 - 0.5	35,100J	27,000
SS66	0.0 - 0.5	536 J	951
SS79	0.0 - 0.5	288 J	602
SS80	0.0 - 0.5	171 J	282
SS86	0.0 - 0.5	240 J	236
SS86 (Rep)	0.0 - 0.5	1370J	212
VP38	2.0 - 2.5	33.9	26
VP40	4.0 - 4.5	15.8J	71.9J
VP77	6.0 - 6.5	9.3	10.7J
BERM16	4.0 - 6.0	61.6J	376J
BERM39	0.0 - 2.0	31,800J	8,270J
BERM52	8.0 - 10.0	1,270J	170J
BERM76	0.0 - 2.0	75,900J	62,700J

[a] mg/kg - milligrams per kilogram
[b] feet bgs - feet below ground surface
[c] "J" = value is an estimated concentration.
[d] Rep - Replicate of previous sample

TABLE C.2-3
COMPARISON OF LEAD CONCENTRATIONS
IN TOTAL AND SIEVED SOIL FRACTIONS FROM THE TEXAS SKEET RANGE

Sampling Location	Sampled Depth Interval (feet bgs)[b/]	Soil Fraction and Associated Lead Concentration (mg/kg)[a/]	
		Total Fraction	<60-Mesh Sieved Fraction[c/]
Surface Samples			
SS01	0.0 - 0.5	13.2 J[d/]	17.0 J
SS01[e/]	0.0 - 0.5	14.0 J	14.1 U[f/]
SS02	0.0 - 0.5	44.1 J	43.6 J
SS03	0.0 - 0.5	84.0	105
SS04	0.0 - 0.5	16.6 J	13.6 J
SS05	0.0 - 0.5	81.5	96.0
SS06	0.0 - 0.5	45.3	40.8 J
SS07	0.0 - 0.5	50.5	50.3
SS07[e/]	0.0 - 0.5	49.8 J	54.9
SS08	0.0 - 0.5	34.3 J	33.0 J
SS09	0.0 - 0.5	48.6	44.5 J
SS10	0.0 - 0.5	143	150
SS11	0.0 - 0.5	174	152
SS12	0.0 - 0.5	85.6	89.2
SS13	0.0 - 0.5	67.9	114
SS14	0.0 - 0.5	39.8 J	56.5
SS15	0.0 - 0.5	56.0	70.4
SS16	0.0 - 0.5	94.8	99.6
SS17	0.0 - 0.5	159	162
SS18	0.0 - 0.5	19.0 J	73.0
SS19	0.0 - 0.5	98.7	88.5
SS20	0.0 - 0.5	246	319
SS21	0.0 - 0.5	319	331
SS21[e/]	0.0 - 0.5	303	327
SS22	0.0 - 0.5	95.3	112
SS23	0.0 - 0.5	42.2 J	28.3 J
SS24	0.0 - 0.5	42.3 J	38.5 J
SS25	0.0 - 0.5	162	144
SS26	0.0 - 0.5	520	489
SS27	0.0 - 0.5	455	679
SS28	0.0 - 0.5	285	307
SS29	0.0 - 0.5	29.1 J	32.4 J
SS30	0.0 - 0.5	13.3 J	10.9 J
SS31	0.0 - 0.5	25.5 J	26.4 J
SS31[e/]	0.0 - 0.5	26.1	23.2 J
SS32	0.0 - 0.5	50.4	43.8 J
SS33	0.0 - 0.5	218	258
SS33[e/]	0.0 - 0.5	230	243
SS34	0.0 - 0.5	350	413
SS35	0.0 - 0.5	176	215

TABLE C.2-3 (Continued)
COMPARISON OF LEAD CONCENTRATIONS
IN TOTAL AND SIEVED SOIL FRACTIONS FROM THE TEXAS SKEET RANGE

Sampling Location	Sampled Depth Interval (feet bgs)[b/]	Soil Fraction and Associated Lead Concentration (mg/kg)[a/]	
		Total Fraction	<60-Mesh Sieved Fraction[c/]
SS36	0.0 - 0.5	49.1	44.6 J
SS37	0.0 - 0.5	106	131
SS38	0.0 - 0.5	179	190
SS39	0.0 - 0.5	23.2 J	26.8 J
SS40	0.0 - 0.5	91.9	78.5
SS41	0.0 - 0.5	92.3	104
SS42	0.0 - 0.5	63.4	54.3
SS42[e/]	0.0 - 0.5	53.3	52.6
SS43	0.0 - 0.5	125	102
SS44	0.0 - 0.5	22.5 J	26.6 J
SS45	0.0 - 0.5	36.3 J	44.2 J
SS46	0.0 - 0.5	52.1	33.7 J
Subsurface Soil Samples			
VP-21	0.0 - 0.5	524	603
	1.0 - 1.5	110	130
	2.5 - 3.0	56.4	61.0
	4.5 - 5.0	21.8	27.4 J
VP-32	0.0 - 0.5	28.0 J	33.3 J
	1.0 - 1.5	8.3 J	13.1 J
	2.5 - 3.0	10.2 J	11.1 J
	4.5 - 5.0	6.2 J	8.4 U

[a/] mg/kg - milligrams per kilogram.

[b/] feet bgs - feet below ground surface.

[c/] Particles less than 250 microns in diameter.

[d/] "J" = value is an estimated concentration.

[e/] Replicate of preceding sample.

[f/] U - Analyte not detected at or above the cited detection limit.

ATTACHMENT C.3

IN-VITRO LEAD BIOAVAILABILITY RESULTS

TABLE C.3-1
IN-VITRO BIOAVAILABILITY
PROTOCOL DOCUMENT
SMALL-ARMS FIRING RANGE DEMONSTRATION

Sampling Location	Sample Depth Interval (feet bgs)[a/]		Bioavailability (percent)
SKEET RANGE, TEXAS			
SS20	0-0.5		64.7
SS20 (Replicate)	0-0.5		63.5
SS26	0-0.5		60.5
SS32	0-0.5		59
SS15	0-0.5		49.1
SS21	0-0.5		60.9
SS27	0-0.5		63.2
		Average:	60.1
SMALL ARMS RANGE, CALIFORNIA			
RBS-4	0-0.25		79
RBS-3	0-0.25		96.2
RBS-6	0-0.25		96.4
RBS-7	0-0.25		75
RBS-8	0-0.25		79.2
		Average:	85.2
SMALL ARMS RANGE, TEXAS			
PR3-2 (Pistol Range No. 2)			81.1
RRA-1 (Rifle Range A)			77.1
RRA-1 Replicate			78.8
RRA-3 (Rifle Range A)			104.8
RRB-4 (Rifle Range B)			65.1
RRC-3 (Rifle Range C)			73.3
RRD-2 (Rifle Range D)			70.1
RRD-2 Replicate			75
RRD-3 (Rifle Range D)			84.9
BM3-1 (Pistol Range No. 3)			90.4
BMA-1 (Rifle Range A)			107.6
BMA-2 (Rifle Range A)			76.2
BMA-2 Replicate			54.7
BMC-1 (Rifle Range C)			71.9
BMD-1 (Rifle Range D)			101.1
		Average:	80.8

[a/] bgs = below ground surface.

APPENDIX D

ECOLOGICAL RISK ASSESSMENT – LESSONS LEARNED

To develop a streamlined risk-based approach to remediation of former Air Force firing-range sites, four abandoned ranges at Air Force installations in Alaska, California, and Texas were investigated to develop, test, and refine sampling, analysis, data evaluation, and risk assessment techniques to be used at firing-range site where soil is the principal contaminated medium. This protocol document is based on the results of the work at the four demonstration sites, which included three rifle ranges and one skeet range. Based on the results of data analysis techniques employed during the demonstration of the risk-based approach, and on regulatory review comments received on the draft remedial action plans (RAPs) prepared for the four sites, this appendix summarizes the lessons learned during performance of the ecological risk assessments (ERAs) for these small-arms firing-range sites. The information provided is intended to assist Air Force remedial project managers (RPMs) in scoping risk-based remedial investigations for firing ranges, and to ensure that ERAs meet Air Force and regulatory objectives, and provide adequate and relevant information for consideration in the risk management and remedial decision-making processes.

D.1 REGULATORY CONSIDERATIONS

For all four demonstration firing-range sites, the respective states (Alaska, California, and Texas) were the lead regulatory authorities. For Clear Air Station (AS) in Alaska, the Alaska Department of Environmental Control (ADEC) served as the lead review agency. For Travis Air Force Base (AFB), California, jurisdiction was shared between the California Regional Water Quality Control Board (CRWQCB) and the California Environmental Protection Agency (CalEPA) Department of Toxic Substance Control (DTSC), Human and Environmental Risk Division (HERD). Because of potential use of the site by a variety of wildlife receptors, HERD also recommended review of the Travis AFB ERA by the California Department of Fish and Game (CDFG). For Goodfellow and Lackland AFBs in Texas, the Texas Natural Resource Conservation Commission (TNRCC) was the lead agency.

Each of these states has published guidelines and/or regulations for conducting ERAs at hazardous waste sites. While the state guidelines all generally follow the ERA paradigm developed by the US Environmental Protection Agency (USEPA, 1997a and 1998a) and summarized in Figure 4.3, the specifics of the requirements vary significantly among the states. The fact that the four demonstration sites lie within three different USEPA regions, two of which have published regional ERA guidelines, also contributed to the differences in requirements for conducting ERAs.

As an example of the differences in the state-specific ERA guidelines, TNRCC (1996 and 1999) requires a tiered approach in which a two-step toxicity-screening process, using soil benchmarks and toxicity reference values (TRVs), is recommended to narrow the list of chemicals of potential concern (COPCs) requiring further risk analysis. The CalEPA (1996) guidelines for performing ERAs, which also outline a tiered approach, do

not permit toxicity screening to reduce the list of COPCs, though comparison of site soil concentrations of metals to background metals concentrations is permitted. ADEC (1998) guidance calls for toxicity screening using screening-level hazard quotients (SLHQs), a chemical's biomagnification potential, and/or quantitative structural activity relationships (QSARs) to refine the COPC list.

State-specific differences in approach, such as the ones outlined above, can significantly affect the methods used in the ERA, and may affect the outcome of the risk analysis as well. Because methodological differences abound in ERA requirements, the Air Force RPM should ensure that the contractor performing the ERA for any site is qualified in the science of exposure modeling and risk analysis, and is familiar with USEPA (1997a and 1998a) and pertinent state ERA guidance. Based on the experiences in performing ERAs under the differing guidelines and regulations at the four firing-range demonstration sites, the need for employing scientific/management decision points (SMDPs), as described in Section 4, cannot be overemphasized. Because of the variations in required ERA methods, the following subsections highlight lessons learned from the risk-based demonstrations that may be relevant regardless of the regulatory requirements, and do not attempt to provide a template for performing the ecological portion of the risk assessment. Air Force project managers are referred to the primary USEPA (1997a and 1998a) guidance documents for ERAs to gain a better understanding of methodological issues.

D.2 PROBLEM FORMULATION CONSIDERATIONS

Problem formulation usually begins with construction of a conceptual site model (CSM) that summarizes exposure hypotheses for ecological receptors based on site conditions and land use. The risk-based investigations at the demonstration sites resulted in identification of factors unique to terrestrial firing ranges that should be taken into account during problem formulation for such sites. These factors are summarized below:

- Target as potential site-related contaminants for laboratory analysis only those analytes that likely are attributable to former use of the site as a firing range. Specify the individual metals to be analyzed for, along with an analytical method that will achieve the necessary detection limits, in the laboratory subcontract and the project work plan. Unless required by the regulating body, avoid "full-suite" analyses (e.g., via USEPA Method SW6010 for metals or Method SW8270 for semivolatile organic compounds) that may result in evaluation of analytes that are not likely attributable to site operations, but that may be present in site soils due to a number of unrelated factors. Focusing the analytical data on relevant firing-range constituents can save time and money.

- Metals and polynuclear aromatic hydrocarbon (PAH) soil contamination related to historical firing-range activities is found at the greatest concentrations within the upper 1 foot of the soil column, and typically decreases significantly in concentration within 3 feet of the surface (assuming site soils have not been disturbed through grading, tilling, etc.). Therefore, evaluation of the upper soil interval (< 2 feet below ground surface [bgs]) is conservative for receptors that also may be exposed to deeper soils (e.g., during burrowing or via root uptake).

- Except in the case of lead shot at former skeet and trap ranges, metals particle size probably is not significant when evaluating risks to plants and wildlife. This is because at rifle/pistol ranges, the majority of the lead occurs in fines that may become available for plant/invertebrate uptake (via dissolution into soil moisture) and that could be incidentally ingested by wildlife.

- Both demonstration sites in Texas were infested with insects that had an impact on the ERA: at one site, harvester ants had concentrated lead shot and small skeet target fragments at the ground surface near the ant hills; at the other, imported fire ants constituted a biological stressor that limited use of the site by small mammals and ground-dwelling birds. These sites demonstrate the importance of considering biological stressors during problem formulation.

- Because of their specialized diets and need to ingest grit, granivorous upland gamebirds (e.g., mourning dove, quail, grouse, pheasant, etc.) should be included among receptors selected for evaluation at skeet/trap ranges where habitat conditions are suitable to support such species. The lead shotgun pellets, and possibly small fragments of skeet/trap targets (i.e., clay pigeons), may be of a size that could be selectively ingested and retained in the crops (gizzards) of such birds.

- Lead speciation, soil pH and cation exchange capacity, toxicity test, and *in vitro* bioavailability data are useful in assessing the potential for uptake by site biota of metals in soil (see Appendix C). Such data should be collected from the soil exposure intervals for ecological receptors.

- In addition to any special-concern species that may be present, select as receptors for evaluation those resident species that have maximum soil contact from the trophic levels represented at the site. Prepare a food-web diagram for each site to help justify receptor selections. A simple food web example is provided as Figure D.1.

- Include all potentially completed pathways in the CSM, including those for which data limitations preclude quantitative risk analysis (e.g., inhalation and dermal contact).

D.3 ANALYSIS CONSIDERATIONS

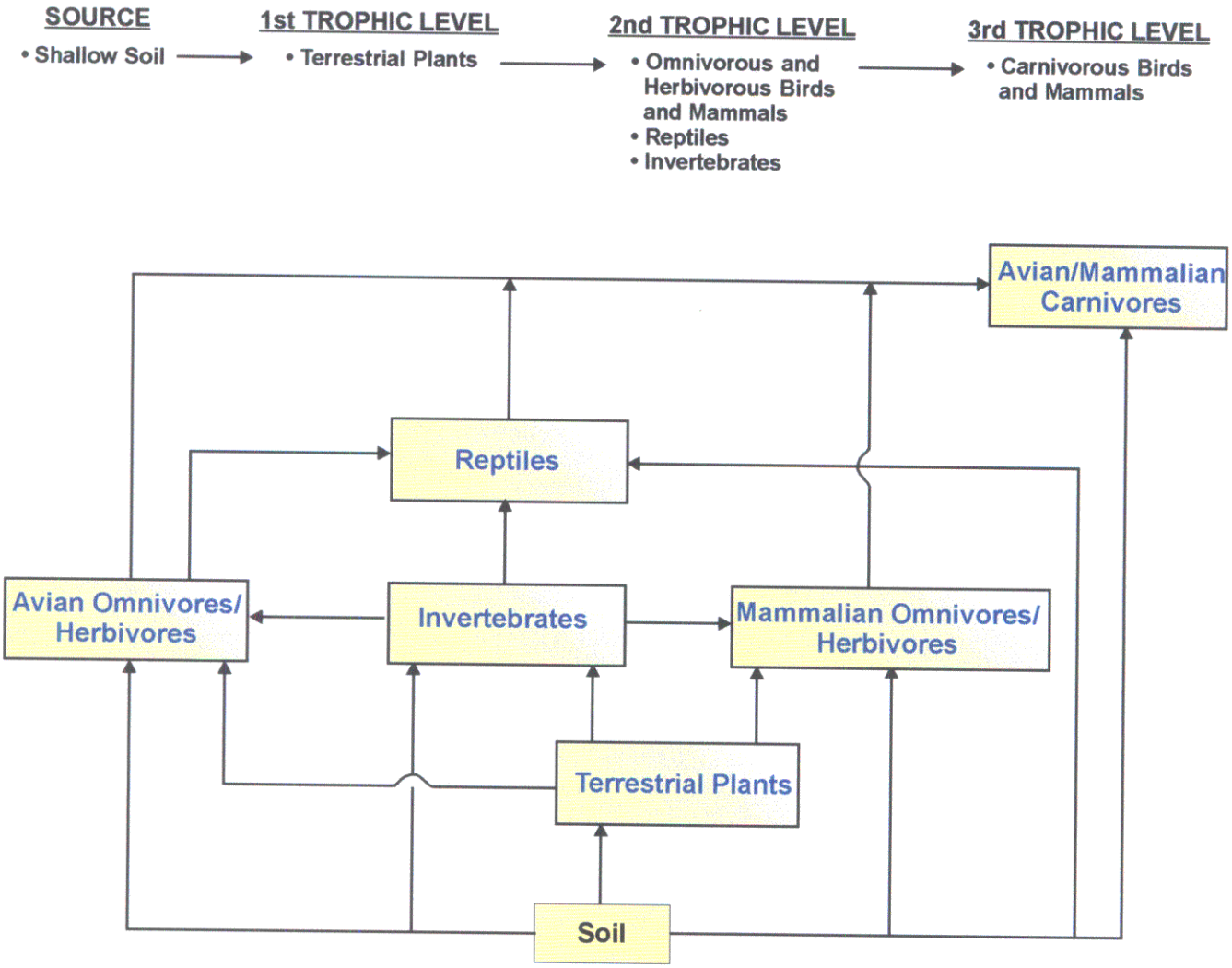
As indicated in Section D.1, many of the procedures to be used in the exposure and toxicity analyses steps of firing-range ERAs are governed by state requirements. Two primary areas in which there may be flexibility in applying the current guidance were identified during the four firing-range ERA demonstrations. One of these relates to estimating receptor doses of COPCs in soil (i.e., the exposure assessment), and the other relates to developing measurement endpoints for the COPCs (i.e., the toxicity assessment).

D.3.1 Exposure Assessment Considerations

In the exposure assessment step, a biokinetic food-web model, such as the one shown in the text box below, typically is used to estimate exposures for wildlife that may ingest

FIGURE D.1

EXAMPLE TERRESTRIAL FOOD WEB



soil and biota contaminated by site COPCs. In the absence of site-specific data on the bioavailability of COPCs, exposure algorithms incorporate the default assumption of 100-percent bioavailability of all COPCs in soil. While it is widely acknowledged that this assumption likely is overly conservative for many chemicals (Dixon *et al.*, 1993; USEPA, 1993b), often there are few data that would allow a departure from this assumption.

Example Exposure Dose Algorithm

Red-tailed hawk average exposure dose (mg/kg/day) =

$$\{[(C_s * BAF * I_a) + (C_s * I_s * ST)] * SFF\} / BW$$

Where:

C_s = COPC exposure-point concentration in soil exposure interval (mg/kg)

I_a = small mammal ingestion rate (kg/day)

BAF = chemical-specific bioaccumulation factor for small mammal prey (unitless)

I_s = incidental soil ingestion rate (kg/day)

ST = bioavailability factor for constituents ingested in soil (unitless)

SFF = ratio of site exposure area to receptor foraging range (unitless)

BW = average adult body weight (kg)

As discussed in Appendix C, *in vitro* bioavailability and speciation analyses were conducted for lead in soil at the four firing-range demonstrations sites. Metals bioassay data from an earlier study also were available for Travis AFB, California. The *in vitro* bioavailability data were successfully used at the demonstration sites in California and Texas to refine the default bioavailability factor (BAF) of 1 (i.e., 100-percent) in the exposure-dose algorithms for higher-trophic-level wildlife receptors that consume mammalian prey (e.g., raptors and foxes). Development of a site-specific BAF for small mammal prey was based on the relationship between lead solubility and lead's absorption in the human digestive tract proposed by the USEPA (1996c) Technical Review Workgroup (TRW) for Lead. TRW recommends as default values an assumed solubility of 60 percent for lead in soil, and an assumed absorption factor of 20 percent following ingestion of lead-contaminated soil. The default BAF of 12 percent is derived by multiplying the assumed solubility and absorbability fractions (i.e., 0.6 x 0.2 = 0.12) (USEPA, 1996c). In using the USEPA formula to estimate a site-specific BAF for mammalian prey, the average site-specific solubility of lead in soil determined from the *in vitro* analyses was used in place of the default value of 60 percent. To account for the uncertainty of extrapolating the human absoption factor to small mammals, that factor was increased from the human default value of 20 percent to 50 percent. The resulting BAF was then used in place of the literature-based BAF for lead in small mammal prey in the exposure algorithm. An example BAF calculation is shown in the following text box.

Example Site-Specific BAF for Small Mammal Prey

$$\text{Site-Specific BAF} = Pb_S \times Pb_A$$

Where:

Pb_S = the average site-specific lead solubility determined from the *in vitro* bioavailability analysis

Pb_A = the assumed absorbable fraction of soil lead in the small mammal gut (50 percent)

Use of the *in vitro* bioavailability data to develop site-specific BAFs resulted in BAFs for small mammal prey that were lower than the literature BAF for lead. A lower BAF results in a lower estimated exposure dose for the predator receptor, which leads to a lower hazard quotient (HQ) in the risk characterization step of the ERA, and a higher risk-based cleanup goal. However, a validation study in which bioassay data are collected and analyzed for correlation to the BAFs developed using *in vitro* bioavailability data should be conducted to reduce uncertainty associated with the extrapolation of BAFs from soil data. During technical review of the draft remedial action plans for the demonstration firing-range sites, it was further determined that the site-specific solubility fraction for lead in soil could be substituted for the default bioavailability factor, ST, in the exposure algorithms for all mammalian receptors, further lowering the estimated lead exposure doses, HQs, and cleanup goals for ecological receptors exposed to lead in soils.

D.3.2 Toxicity Assessment Considerations

The toxicity assessment involves using measurement endpoints to assess the potential for adverse effects on the assessment endpoints from exposure to site-related COPCs. For states where a benchmark screening step is required, literature soil benchmarks that typically are predicated on no-observed-adverse-effect levels or concentrations (NOAELs or NOECs) are recommended. Where screening-level hazard quotients (SLHQs) are used, the comparison value also is based on NOAELs or NOECs, which are researched in the literature and then extrapolated for the representative receptors as toxicity reference values (TRVs). These conservative TRVs often are also used to develop HQs in the risk characterization step.

A USEPA national workgroup is in the process of developing ecological soil screening levels (EcoSSLs) that are intended to be used as standardized screening values for use in ERAs. Until the EcoSSLs are published, however, toxicity research through the scientific literature and on-line databases is required to identify appropriate receptor- and chemical-specific measurement endpoints for most ERAs. During such research for terrestrial firing-range sites, care should be taken to identify appropriate toxicological data for extrapolation to site wildlife. These data should consider the chemical species used in the toxicity tests, the subject animal species tested, and the method of exposure. The latter is particularly important, as the use of drinking water or gavage studies (for example) may overestimate the potential toxic effects associated with ingestion of contaminants in food

or soil. Review of site-specific lead speciation data may be useful assessing the relevance of available toxicity data to lead present at the site.

The risk-based approach at the demonstration sites also proposed the use of lowest-observed-adverse effect levels and concentrations (LOAELs and LOECs) as the measurement endpoints to assess toxicity and estimate risks to ecological receptors at the population level. Where accepted by the regulators, use of LOAELs instead of NOAELs can reduce the HQs and the proposed cleanup goals for protection of ecological receptors. As noted in Section 4.4, use of NOAELs rather than LOAELs is appropriate for receptors that are threatened, endangered, or rare.

D.4 RISK CHARACTERIZATION AND RISK MANAGEMENT CONSIDERATIONS

The site-specific information discussed in Sections D.2 and D.3 can directly affect the risk characterization step of the ERA process. Tailoring default exposure assumptions and measurement endpoints to better reflect site conditions, receptors, and land uses can directly influence the magnitude of the hazards estimated using HQs. Lower HQs lead to higher cleanup goals that are still protective of the ecosystem at risk at a former firing-range site. This is particularly important at abandoned firing ranges, where potential ecological risks may outweigh risks to human receptors, and therefore may drive site cleanup.

For the risk-based demonstration sites, a range of proposed chemical-specific, numerical cleanup goals was presented for each assessment endpoint (represented by the receptors evaluated). The range was based on HQs derived using both NOAELs and LOAELs using target HQs of 1 (for NOAEL HQs) and 10 (for LOAEL HQs), as well as on background concentrations for the metals chemicals of concern (COCs). From the range of values presented for each site, a single cleanup goal was proposed for each COC.

Final site cleanup goals are selected during the risk management process. Historically, ecologically based soil cleanup goals have typically been based on target NOAEL-based HQs of 1. However, effective use of scientific/management decision points (SMDPs) throughout the ERA process, and clear documentation of the risk-based methods used in the ERA can facilitate negotiation of cleanup goals that are reflective of the prevailing site conditions and expected future land uses. Based on the ERAs for the demonstration firing ranges, proposed cleanup goals based on target LOAEL-based HQs of 10 were approved by the reviewing regulatory agencies. At one site, soil cleanup goals for lead of 40 to 61 parts per million (ppm), which were proposed in the previous ERA for the site, were renegotiated to a goal of 1,000 ppm using the risk-based approach outlined in this protocol. The higher cleanup goal was developed using a target LOAEL HQ of 10 for the most sensitive resident receptor evaluated as an assessment endpoint. As this example demonstrates, familiarity with ERA methods and current thinking, supplemented with ongoing, constructive dialogue with decision-makers throughout the course of the project, can yield significant dividends during the risk-management phase of site restoration.

APPENDIX E

SIMULATED REMEDIATION APPROACH

A fundamental tenet of the risk-based approach to remediation of firing-range sites holds that remedial action objectives (RAOs) will be met if the exposure point concentrations (EPCs) for the chemicals of concern (COCs) in soils are reduced below the respective risk-based cleanup goals . This section describes the process to be used to determine which soils require remediation in order to meet the RAOs (Figure E.1). In general, the process involves simulating cleanup scenarios by removing specific areas of soil based on available investigation results. These localized areas contain elevated COC concentrations that exceed the cleanup goals, and therefore may pose unacceptable risks to potentially exposed receptors. Simulated remediation involves the iterative replacement of sampling data with a surrogate value, representing remediated conditions, and recalculation of the 95-percent upper confidence limit (UCL) for the exposure interval based on the new data set for comparison with the risk-based remediation goals. This process is described in greater detail below.

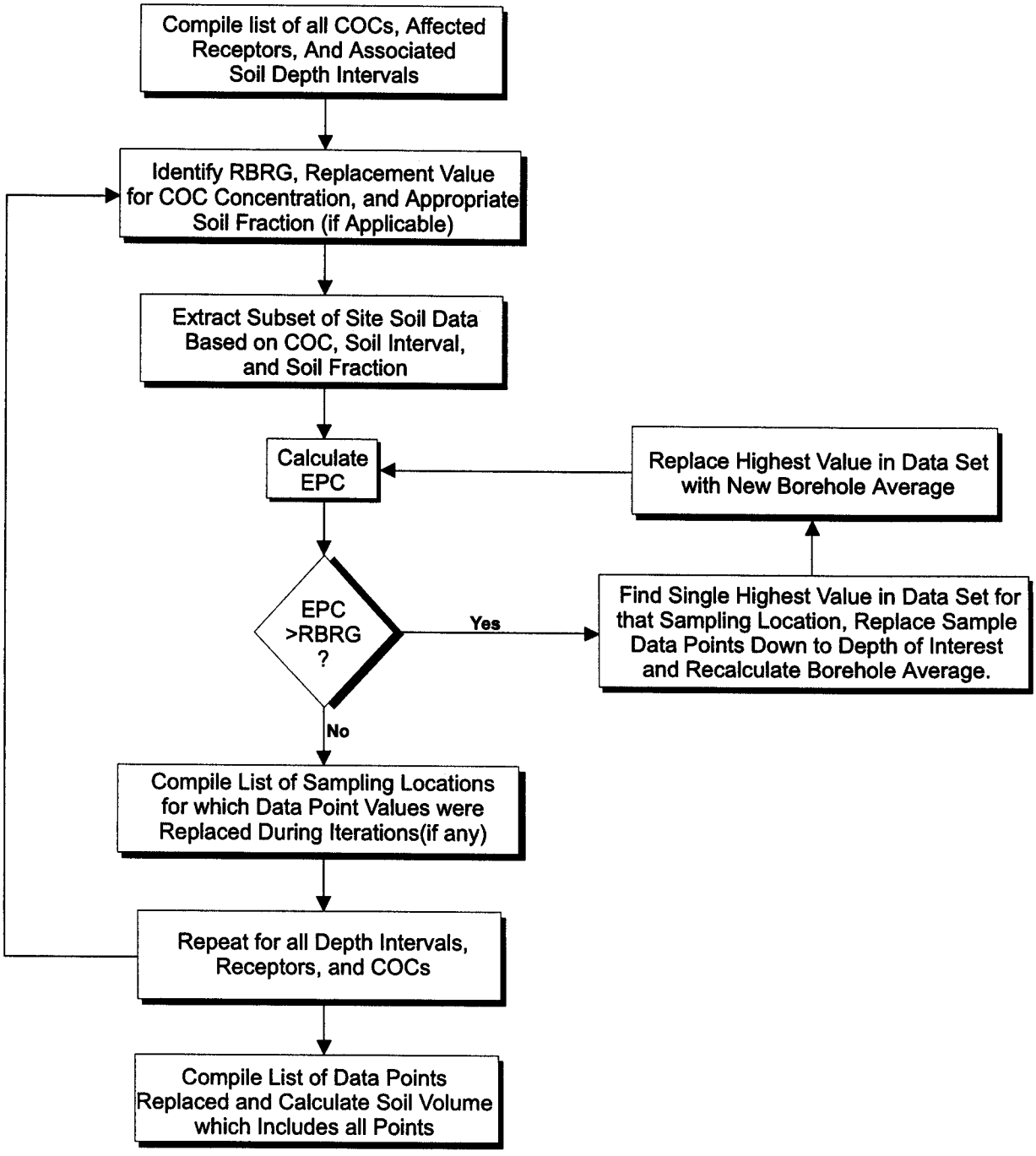
EPC = Exposure Point Concentration....

.... A statistically derived value that is representative of the central tendency of contaminant concentrations (such as lead) at a site. When available, the EPC can be used for risk evaluations, rather than using the maximum concentration at a site, to represent risk to a potential receptor, on average.

Soils requiring remediation are determined with consideration of both the ecological and human health risk analyses. Receptors are assumed to be exposed to the COCs in the soil exposure intervals evaluated in the risk analysis. Determination of soil "hot spots" requiring remediation is based on receptor exposures to these contaminants (i.e., completed exposure routes). If a contaminant is retained as a COC but the recommended

FIGURE E.1

PROCESS FOR IDENTIFICATION OF SOILS REQUIRING REMEDIATION



NOTES:

COCs = Chemicals of Concern

RBRG = Risk-Based Remediation Goal

EPC = Exposure-Point Concentration
(95-Percent Upper Confidence Limit on the Mean)

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risk-based cleanup level for the contaminant is greater than its site-wide EPC, then no remediation is required for that contaminant (i.e., the COC is present, on average, at concentrations at or below the recommended cleanup goal).

Simulated Remediation....

.... Manipulation of site data to determine the minimal volume of soil that requires remediation to meet cleanup levels.

Data manipulations using site characterization data are performed to simulate the soil remediation required to meet RAOs. The simulated soil remediation scenarios are based on ecological and/or human receptors exposed to a particular COC in the soil exposure intervals developed in the risk assessment.

The first step is to remove the sample result with the highest COC concentration from the original data set and replace it with a surrogate value (e.g., the risk-based cleanup goal). Next, the 95- percent UCL (i.e., the EPC) for the new set data is calculated and compared to the risk-based cleanup goal for that COC. If the 95-percent UCL exceeds its respective cleanup goal, the next highest detected COC concentration is removed from the data set, replaced with the surrogate (replacement) concentration, and the 95-percent UCL for the data set is recalculated. This iterative procedure is repeated until the 95-percent UCL for the COC is less than the risk-based cleanup goal.

This procedure is conducted first for the shallowest soil exposure interval as defined in the risk assessment. If a risk-based cleanup level was estimated for other deeper expsoure intervals, the above process is then repeated. Specifically, once the 95-percent UCL for the COC is less then the cleanup level in the shallow soil exposure interval, then the 95-percent UCL is calculated for any deeper soil exposure intervals. If the EPC is greater than the deeper interval cleanup level, the iterative process (replacement of highest concentration results) is performed until the 95-percent UCL is less than the cleanup level. In most cases, the data set resulting from "virtual remediation" of the shallow interval is sufficient to cause the EPCs for deeper intervals to be less than the deeper interval cleanup levels.

For all remediation analyses, the bootstrap method, a nonparametric statistical procedure, should be used to estimate the 95-percent UCLs for the COCs. The bootstrap method requires no assumptions regarding the statistical distribution of the data (e.g., normal or log-normal), can be applied to a variety of situations, and "may result in a significant reduction in remediation costs" (USEPA, 1997c). Use of a nonparametric method eliminates the need to perform distribution analyses on the data sets each time a value is removed and replaced. In addition, nonparametric statistical methods (such as the bootstrap method) are relatively insensitive to sample size (n) and can provide a better estimate of the mean than parametric methods applied to normal or log-normal distributions when n is small.

The surrogate value to be substituted for hot-spot concentrations is based on the specific technology evaluated for remediation. Common soil remediation technologies include soil removal/offsite disposal and soil treatment. For soil removal/offsite disposal, the surrogate values for the COCs are established to represent a conservative (high-end)

approximation of concentrations in clean backfill soils that could be used at the small-arms range. For remediation by soil treatment technologies, removal of metals to near-background concentrations of metals is not likely to be attainable due to limitations in treatment technologies; therefore, the COC-specific cleanup values can be used as surrogate values to represent attainable treatment criteria.

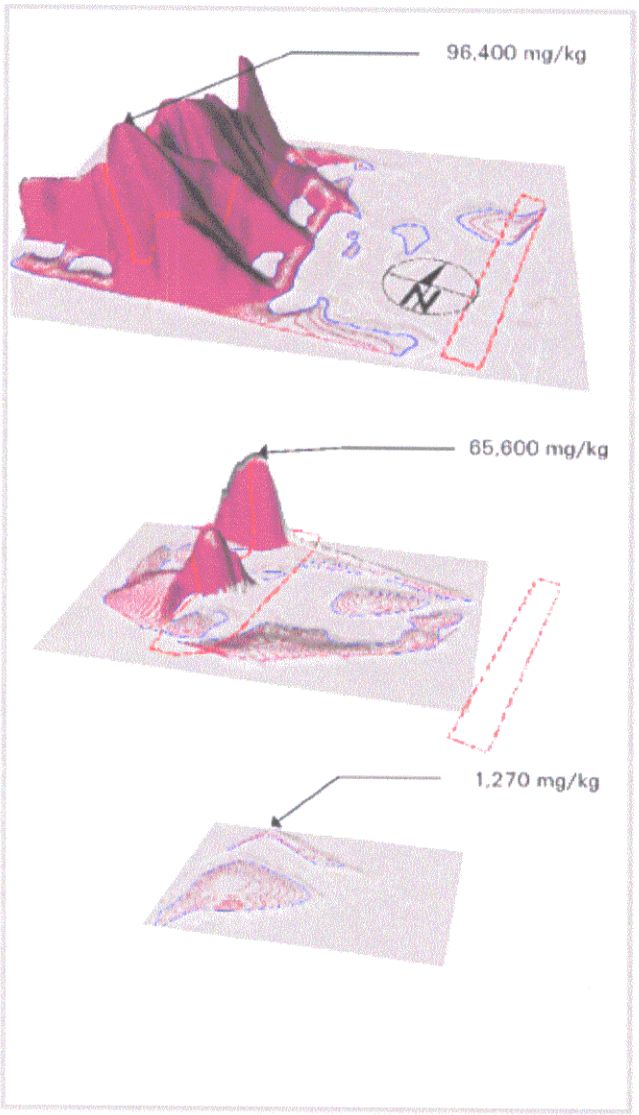
The result of this approach is a definition of the specific volumes of contaminated soil requiring remediation. Additional site soils may be remediated (in addition to those prescribed by the "virtual remediation" process) in order to provide a configuration of soils amenable to the proposed remediation technology. For example, if the "virtual remediation" exercise prescribes remediation of a number of separate soil parcels, the soil between those parcels may also be recommended for remediation.

Figure E.2 shows baseline lead concentration with depth at the Texas small-arms range site before remediation (i.e., under the No Action general response action), and Figure E.3 presents the concentrations resulting from remediation of the described soil units by soil removal and disposal. As shown on the figures, some areas outside the cleanup boundaries retain soil lead concentrations that slightly exceed the designated cleanup goal of 500 milligrams per kilogram (mg/kg). However, average site lead concentrations (i.e., the lead EPC for the site exposure area and soil interval) will be less than the lead soil cleanup level following remediation to the limits shown. Therefore, removal or treatment as described in Figure E.3 will meet the RAOs for the site. Although only lead concentrations are shown on these figures, attainment of RAOs for other non-lead metals also is predicted because the remediation for lead typically addresses other metals as well.

USEPA. 1997. *The Lognormal Distribution in Environmental Applications*. Office of Research and Development and Office of Solid Waste and Emergency Response. EPA/600/R-97/006. December.

FIGURE E.2

TOTAL LEAD IN SOIL BEFORE REMEDIATION



Sample Depth

0 to 2 feet bgs

2 to 6 feet bgs

> 6 feet bgs

Legend

0-500 mg/kg Lead

500 mg/kg Lead Risk Based Remediation Goal

Greater than 500 mg/kg Lead

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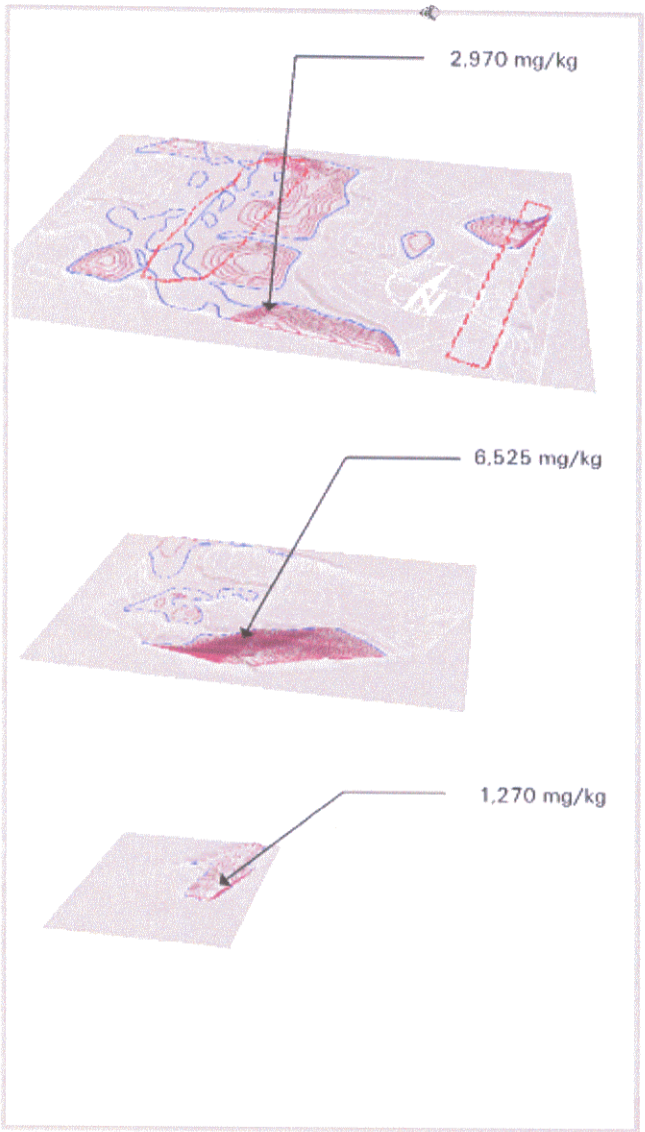
FIGURE E.3

TOTAL LEAD IN SOIL AFTER REMEDIAITON



Sample Depth

0 to 2 feet bgs

2 to 6 feet bgs

> 6 feet bgs

Legend

0-500 mg/kg Lead

500 mg/kg Lead Risk Based Remediation Goal

Greater than 500 mg/kg Lead

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APPENDIX F

EXAMPLE SOILS TREATABILITY TEST PLAN

Soil remediation can often be presumed to be required for some portion of a small-arms range site soils due to high concentrations of lead. Therefore, treatability testing is recommended to identify a cost-effective treatment method for soils. The following is an example test plan for bench-scale treatability testing of small-arms range soils. This example plan is also applicable for skeet and trap range soils.

F.1 TECHNOLOGIES TO BE EVALUATED

Potentially Applicable Soil Treatment Technologies:

- Physical Beneficiation (Particle Size and Density Separation)
- Acid Leaching
- Stabilization

F.1.1 Physical Beneficiation

Physical beneficiation includes a variety of material handling techniques that historically have been used for initial processing of metal-bearing ores in the metallurgical industry. Physical beneficiation segregates soil particles according to size and differences in specific gravity to achieve separation of the "light" materials from the "heavy" materials. Because both sizing and gravity separations are performed on slurried soils, physical beneficiation can be described as soil washing.

A screen can be used to separate differently sized particles. Passing the contaminated soil over a screen with openings slightly larger than the largest lead shot fragment can remove the larger rocks and soil particles and therefore render this larger particle-size fraction as relatively lead-free. The soil that passes through the first screen is passed over a second screen with smaller openings to capture most of the lead projectiles and fragments and little of the soil. This screen may capture a large majority of the lead (up to 95 percent of the total mass of lead contaminants according to some studies) from the soil in a "concentrate" that is salable to a smelter. Thus, screening can be a simple way to remove a large portion of the lead at low cost. Full-scale application of screening generally involves use of a trommel, which is a rotating cylindrical screen used industrially for ore processing and sand and gravel operations.

Physical Beneficiation:

- Size screening, then
- Density separation (generally jigs, spirals, or tables), resulting in
- Concentrated lead fraction, and
- Relatively clean soil tailings.

Lead has a much higher specific gravity than most other minerals and metals that comprise soil. After the large particles of lead are removed by screening, gravity separation devices such as jigs, hydrocyclones, spirals, tables, or water elutriation columns (operated separately or in combination) should be used to separate residual lead from the soil. All of these devices treat a water/soil slurry. Gravity separation techniques work well on uniform-particle-size feed from which the very fine particles (i.e., clays and silts) have been removed. If the very fine particles carry appreciable lead concentrations, this method is less effective.

The effectiveness of screening and gravity separation for lead removal can be assessed in a bench-scale treatability study. Capital and operating costs of physical beneficiation techniques are relatively low compared to other treatment costs, such as stabilization or acid leaching. Further, beneficiation has been successfully applied in pilot- and full-scale systems on firing-range soils.

- **Case Study:** At the Naval Weapons Station Earle Sites 24 and 25, more than 99 percent of the particulate lead was removed from berm material using size and gravity separation techniques, allowing for reuse of more than 95 percent of the soil. Approximately 5 percent of the soil from this site, consisting of clay fines that were separated during soil washing, could not be reused because the total lead concentrations exceeded the cleanup criterion of 400 parts per million (ppm) (Warminsky *et al.*, 1997).
- **Case Study:** A full-scale demonstration at Fort Polk used beneficiation for bulk lead removal. Additional treatment by acid leaching was required at this site to meet the cleanup criteria of 500 mg/kg total lead and less than 5 milligrams per liter (mg/L) for the toxicity characteristic leaching procedure (TCLP) for lead (Warminsky *et al.*, 1997).

F.1.2 Acid Leaching

Acid leaching removes lead from soils by dissolving the lead in an acid and recovering the lead from solution. This is a practice commonly used in the mining and mineral extraction industries. Common leaching reagents for lead removal include hydrochloric acid.

Acid leaching is most effective for removing fine lead particles. Large particles of lead cannot be dissolved cost-effectively. Therefore, physical beneficiation operations

would be necessary to remove the larger lead shot fragments from the soil. Leaching then would be applied to the finer particle sizes.

Acid leaching may not be warranted if the soil contains significant amounts of calcareous matter (such as limestone or caliche), because the basic nature of the soil would require a large amount of acid to acidify the solution. An initial indication of soil suitability could be made from inexpensive soil pH testing.

Site-specific data can be obtained using a representative soil sample that has been processed by physical beneficiation. Treatability testing could include:

- Leaching tests of various concentrations of each potential leaching agent.
- Determination of the effects of time and temperature on lead extraction.
- Evaluation of soil suitability.
- Testing of solution purification and lead recovery procedures to determine those most appropriate for the volumes and concentrations produced from remediation of the former skeet range site.

Case Study: Acid leaching of firing-range soils using acetic acid and hydrochloric acid was evaluated at Fort Polk, Louisiana. Results indicated that hydrochloric acid can be used to meet most leachable standards; however, acetic acid was not effective at this site (Battelle, 1997).

Leaching costs generally are high compared to stabilization, which is described in Section F.1.3. The high costs result from increased soil and reagent handling, the cost of acid leach reagents, and additional handling or residual waste streams associated with acid leaching.

F.1.3 Solidification/Stabilization

Solidification is the encapsulation or physical adhesion of waste on a micro or macro scale into a more solid material. Stabilization is the conversion of contaminants into a less soluble, less mobile, or less toxic form [U.S. Environmental Protection Agency (USEPA), 1989c]. Stabilization/solidification (S/S) is recognized by USEPA (1997b) as an effective remediation process for treatment of soils contaminated with lead and other metals. The applicability of S/S technologies at metals-contaminated sites with environmental contamination is demonstrated by its widespread use (chosen at 26 percent of sites through fiscal year 1992) in remedial actions at metals-contaminated Superfund sites (Means *et al.*, 1995). S/S technologies and applications have been described in detail in numerous publications (USEPA, 1986; USEPA, 1989c; Conner, 1990; Anderson, 1994; and Means *et al.*, 1995).

S/S can reduce contaminant mobility or solubility, improve waste handling by removing free liquids, and decrease the surface area across which transfer of contaminants occurs. S/S technologies include treatment with Portland® cement, pozzolanic materials such as fly ash or lime kiln dusts, phosphorus-based chemical

fixation, and emulsion fixation. Bench-scale treatability testing is usually performed to select the optimum additives and proportions.

Successful treatment of lead-contaminated materials results in reduction of leaching potential below regulatory levels, which usually are based on leachable lead values. A standard simulated weathering test, such as TCLP, multiple extraction procedure (MEP), or synthetic precipitation leaching procedure (SPLP), is typically conducted for evaluation of laboratory-stabilized soils. Some vendors claim success with stabilization of firing-range soils without removal of lead fragments. However, greater protection of human health and the environment occurs when physical beneficiation is used to remove larger pieces of lead prior to the stabilization process.

S/S technology is most promising where future site access is relatively secure, such as continued use as a military base, because the lead will remain in the soil and may continue to pose a potential risk. Long-term monitoring and record keeping are necessary to ensure that lead stabilization remains effective.

F.2 OBJECTIVES OF TREATABILITY TESTING

The purpose of a bench-scale treatability study is to identify the most cost-effective treatment(s) that can effectively reduce the potential risk to human health and the environment posed by exposure to lead in the soil at the range site. Therefore, the overall objective of the treatability testing is to evaluate technologies that can remove lead from the soil or stabilize lead within the soil.

Specific objectives should include the following:

- Determine the distribution of lead particle sizes in skeet range soils to support the risk assessment and feasibility study.
- Determine the quantity of lead that can be removed from skeet range soils using physical beneficiation. This will include assessing the effectiveness of physical and gravity separation to remove lead in soil to the default action levels described below.
- Assess the effectiveness of stabilization of soil that has undergone physical/gravity separation pretreatment for lead removal, and that does not meet the default total lead action level.

For the treatability testing, the effectiveness of each method should be based on the following default post-treatment criteria:

- Total lead concentration of less than 400 mg/kg, which is a conservative residential action level that is protective of human health (USEPA, 1994a); and
- TCLP lead concentrations of less than 5 mg/L.

These criteria will be used only for internal comparisons during the treatability study. Site-specific action levels need to be developed in the remedial action plan (RAP) for the site.

F.3 TREATABILITY TEST DESIGN

A generalized flow diagram for the treatability testing is shown on Figure F.1. This figure describes the samples to be analyzed by the treatability study laboratory and those samples to be analyzed by the contract laboratory for verification analysis. The treatability test design is described below.

F.3.1 Initial Analyses and Sample Preparation

The treatability study sample will consist of approximately 60 kilograms (approximately 125 pounds) of soil in two 5-gallon sample containers. The bulked sample will be collected by compositing soil from multiple locations from within the impact area of the site. The soils will be thoroughly homogenized by mixing in the field prior to placing the soil in the sample container for shipment to the treatability study laboratory.

At the treatability study laboratory, initial total lead analyses will be obtained from the head sample by first removing the particulate lead and determining the metal contribution on a mass basis, followed by total lead analysis by X-ray fluorescence (XRF; or other approved method) on the remaining fraction. Both the mass metal results and analytical results will be factored into generating a raw soil basis. Split samples should be obtained for the soils fractions identified in Figure F.1 by passing the bulk sample through a splitter, and performing confirmation analysis for total lead by Method SW6010B and TCLP lead by SW1311/6010B by a contract laboratory.

F.3.2 Physical Separation

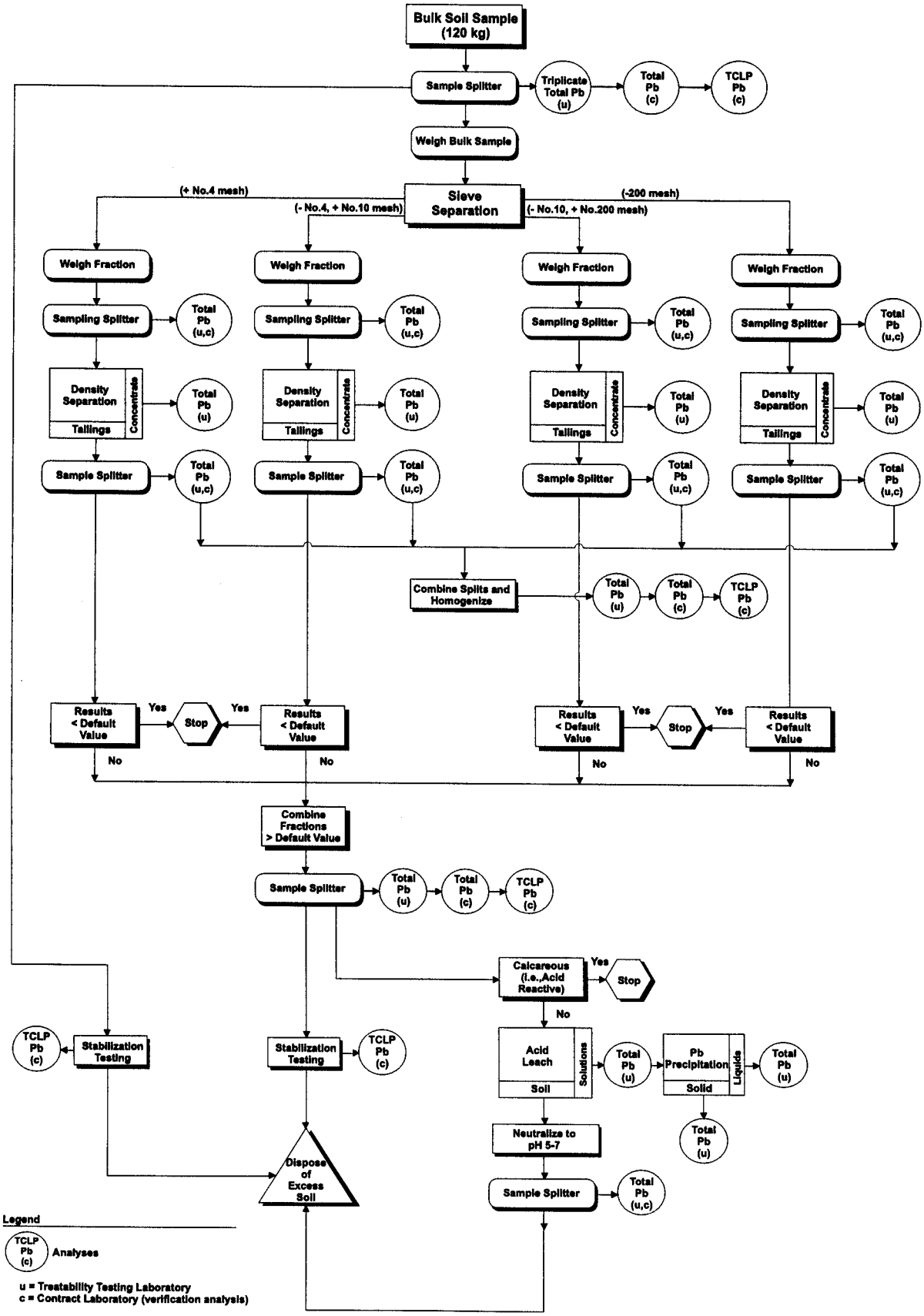
The bulk sample should be weighed, and then wet screened through a set of sieves for separation into the following size fractions:

- A – Greater than No. 4 mesh sieve (greater than 4.75 millimeters [mm]);
- B - Smaller than No. 4 mesh and greater than No. 10 mesh sieve (between 4.75 and 2.0 mm);
- C - Smaller than No. 10 mesh and greater than No. 200 mesh sieve (between 0.075 and 2.0 mm); and
- D - Smaller than No. 200 mesh sieve (clay/silt-size particles less than 0.075 mm).

Each of these size fractions should be weighed, passed through a splitter, and then analyzed for total lead using XRF (or other approved method) by the treatability study laboratory. Split samples from each fraction should be sent to the contract laboratory for confirmation analyses.

FIGURE F.1

FLOW DIAGRAM FOR TREATABILITY TESTING



Note:
One soil sample will also be analyzed for lead by multiple extraction procedure (MEP). See section F.3.6. for sample selection criteria.

F.3.3 Density Separation

Additional separation of lead particles from soil using density separation techniques should be evaluated as appropriate for each of the sieve size fractions. The selection of which density separation technique to use will be based on:

- Results of the size separation methods described in Section F.3.2;
- The judgment and experience of the technician performing the work;
- Expected cost-effectiveness of using the technique for full-scale treatment of site soils; and
- Results from similar applications reported in literature.

Density separation will result in two streams for each size fraction evaluated: a heavier lead-concentrate stream, and a lead-depleted tailings stream. Density separation may include any or all of the following:

- Hydrocyclone separation of the three smallest size fractions (A, B, and C, listed in Section F.3.2);
- Jig separation of the two intermediate size fractions (A and B);
- Table separation of the smaller intermediate size fraction (B); and/or
- Reichert spiral separation of the smaller intermediate size fraction (B).

Analytical testing should be performed by the treatability study laboratory as needed to assess the effectiveness of each separation technique, including testing of the lead content in both the concentrate stream and the tailings stream (Figure F.1). Total lead in concentrates should be assessed gravimetrically, while total lead in tailings should be assessed using XRF analysis (or other approved method). Additional analyses should be performed at the contract laboratory to verify the concentrations of total lead in the lead-depleted tailings samples for each separation technique under consideration for full-scale application (one sample per tailings sample).

Following density separation, approximately one-eighth of the tailings from each size fraction should be split out, and a composite tailing sample should be re-combined from the splits. This recombined sample should be analyzed for total lead using XRF analysis by the treatability study laboratory, and an additional sample should be sent to the contract laboratory for total lead and TCLP lead analysis. The results of this testing will be compared to the post-treatment criteria described in Section F.2.

The total lead results for each tailings stream from density separation also will be compared to the post-treatment criteria for total lead described in Section F.2. Each fraction that fails the total lead criterion should be recombined into a bulk sample for additional treatability testing by stabilization, as described below. In this manner, portions of the soil that meet treatment criteria will be removed from the more contaminated soil prior to secondary treatment.

The recombined sample should be passed through a sample splitter, and should be analyzed for total lead by the treatability study laboratory using XRF analysis. An additional sample should be sent to the contract laboratory for total lead and TCLP lead analysis.

F.3.4 Acid Leaching

If the soil is shown not to be calcareous or acid reactive, acid leaching should be performed to assess the effectiveness of this technique on site soils. The specific soil fractions to be tested will be selected based on the requirement for additional treatment of each fraction, as well as the ability to suspend soils within the fraction into a slurry.

Hydrochloric acid can be tested on an exploratory basis to determine the potential for leaching lead metal in soils. The tests should be performed at ambient temperature for 1 hour with constant stirring which should be vigorous enough to keep all solids suspended in the solution. The leachate should then be drained from the soil, and the soil should be neutralized to a pH of 5 to 7 by addition of caustic.

The treatability study laboratory should perform onsite analyses of total lead in both the residual soil and the leachate solution to assess the effectiveness of lead removal. An evaluation of chemical precipitation (i.e., by pH adjustment) for removal of lead from the leachate should also be performed by the treatability laboratory. Total lead and TCLP-lead analyses of one sample of the leached soil should also be performed by the contract laboratory for definitive confirmation of the results.

F.3.5 Stabilization/Solidification Testing

Soil residuals may require additional treatment to meet project performance goals. Therefore, an evaluation of S/S of the recommended tailing stream can be performed to meet the anticipated treatment goals of less than 5 mg/L of TCLP lead in the resulting soil. In addition, stabilization of the untreated bulked soil can be performed to determine the necessity of separation techniques prior to stabilization.

Non-proprietary reagents should be used for the evaluation of S/S treatment, with emphasis on materials that are locally available in the vicinity of the site. The proposed reagent for this test is Type I Portland cement because this material has been demonstrated to be cost-effective for stabilizing lead-contaminated soil. If the results of treatability testing suggest that stabilization is a likely candidate technology for the site, evaluation of additional stabilization reagents can be performed during the pilot or design stage to identify the most cost-effective reagents and application rates. Initial and final TCLP lead analyses should be performed by the offsite fixed-based laboratory for definitive confirmation of the treatability results.

F.3.6 Multiple Extraction Procedure

For the bulk sample that undergoes treatability testing, one soil sample from within the treatment train should be analyzed for MEP to verify the long-term effectiveness of the treatment process. The soil sample to be selected for MEP analysis should have met the TCLP criterion for lead (i.e., will be nonhazardous) and should be selected as close to the

beginning of the treatment train as possible. For example, if initial testing indicates that the untreated soil will pass TCLP, then an additional sample of the untreated soil should be analyzed for MEP to assess long-term stability. However, if the initial bulk sample and subsequent unstabilized samples fail TCLP, then the stabilized soil also should be analyzed by MEP to assess the long-term effectiveness of treatment. A total of one MEP analysis should be performed.

F.4 DATA ANALYSIS AND REPORTING

Data analysis will include a description of procedures used, an assessment of the overall effectiveness of the treatment techniques evaluated, and development of recommendations for a treatment train to be tested at the pilot scale. The results and conclusions of the treatability study should be presented as an appendix to the RAP for this site.

The treatability test report should include the following components:

- Testing overview;
- Procedures for each treatability testing component, including sample weights, equipment and reagents used, and test methods;
- Test results;
- Mass balance calculations for lead during the testing, including identification of potential areas of uncertainty in the evaluation;
- A conceptual scale-up design and cost estimate for pilot-scale treatment based on the treatability study results; and
- Conclusions and recommendations.

F.5 Management Of Treatability Test Derived Wastes

All soil and residual materials sent to the treatability study laboratory should be disposed of appropriately by the laboratory. It is anticipated that the bulk soil samples will not meet the TCLP criterion for lead, and will require disposal as hazardous waste. Liquid wastes should be neutralized as appropriate and disposed of into the sanitary sewer.